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PROGRESS IN RADAR SNOW RESEARCH

Remote Sensing Laboratory
RSL Technical Report 410-1

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February 1981

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16. Abstract

Multifrequency measurements of the radar backscatter from snow-covered terrain were made at several sites in Brookings, South Dakota, during the month of March of 1979. The data are used to examine the response of the scattering coefficient, σ^o , to the following parameters: (1) snow surface roughness, (2) snow liquid water content, and (3) snow water equivalent. The results indicate that σ^o is insensitive to snow surface roughness if the snow is dry. For wet snow, however, surface roughness can have a strong influence on the magnitude of σ^o. These observations confirm the results predicted by a theoretical model that describes the snow as a volume of Rayleigh scatterers, bounded by a Gaussian random surface. In addition, empirical models were developed to relate σ^o to snow liquid water content and the dependence of σ^o on water equivalent was evaluated for both wet and dry snow conditions.

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NOMENCLATURE

I^+, I^-	Upward (+) and downward (-) intensity matrices
I_s^+, I_s^-	Direct intensities, upward (+) and downward (-)
I^i	Incident scattering intensity
m_v	Snow liquid water content, % by volume
P	Rayleigh phase matrix
R_g	Ground reflectivity
S_R	Surface scatter function
S_T	Transmitted bistatic scattering coefficient
t	time, hours
t_s	time shift, hours
W	Snow water equivalent, cm
Δ	The change in
$\partial\sigma^o/\partial m_v$	Sensitivity of σ^o to m_v changes
ϵ_r	Relative dielectric constant of snow
θ	Angle of incidence
μ	$\cos\theta$
ρ	Correlation coefficient
σ^o	Backscattering coefficient, dB
τ	Optical depth
ϕ	Azimuth angle
ω	Albedo

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PROGRESS IN RADAR SNOW RESEARCH

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ABSTRACT

Multifrequency measurements of the radar backscatter from snow-covered terrain were made at several sites in Brookings, South Dakota, during the month of March of 1979. The data are used to examine the response of the scattering coefficient, σ°, to the following parameters: (1) snow surface roughness, (2) snow liquid water content, and (3) snow water equivalent. The results indicate that σ° is insensitive to snow surface roughness if the snow is dry. For wet snow, however, surface roughness can have a strong influence on the magnitude of σ°. These observations confirm the results predicted by a theoretical model that describes the snow as a volume of Rayleigh scatterers, bounded by a Gaussian random surface. In addition, empirical models were developed to relate σ° to snow liquid water content and the dependence of σ° on water equivalent was evaluated for both wet and dry snow conditions.

1.0 INTRODUCTION

Several experiments were conducted in the past few years to establish the response of the radar backscattering coefficient, σ^o, to snowpack properties. A 1978 literature review of the subject is available in Ulaby et al. (1978). Since the above review, the results of a 1977 experiment were recently published (Stiles and Ulaby, 1980; Ulaby and Stiles, 1980) in which the spectral, angular and polarization dependence of σ^o on snow properties were examined. These results provided information on the overall behavior of σ^o as a function of snow water equivalent, snow wetness, and the moisture content of the underlying soil medium, but many questions regarding the detailed behavior remain unanswered.

In 1979, an experiment was conducted at several sites in Brookings, South Dakota. The experiment description and results are the subject of this report.

2.0 EXPERIMENT DESCRIPTION

2.1 Test Sites

Three areas near Brookings, South Dakota were selected as test sites for the radar (Figure 2.1) and ground truth data acquisition. These sites were selected to provide variation in ground characteristics and snow depth.

The first site was a corn-stubble field at the South Dakota State University Agricultural Engineering Research Unit. After the corn had

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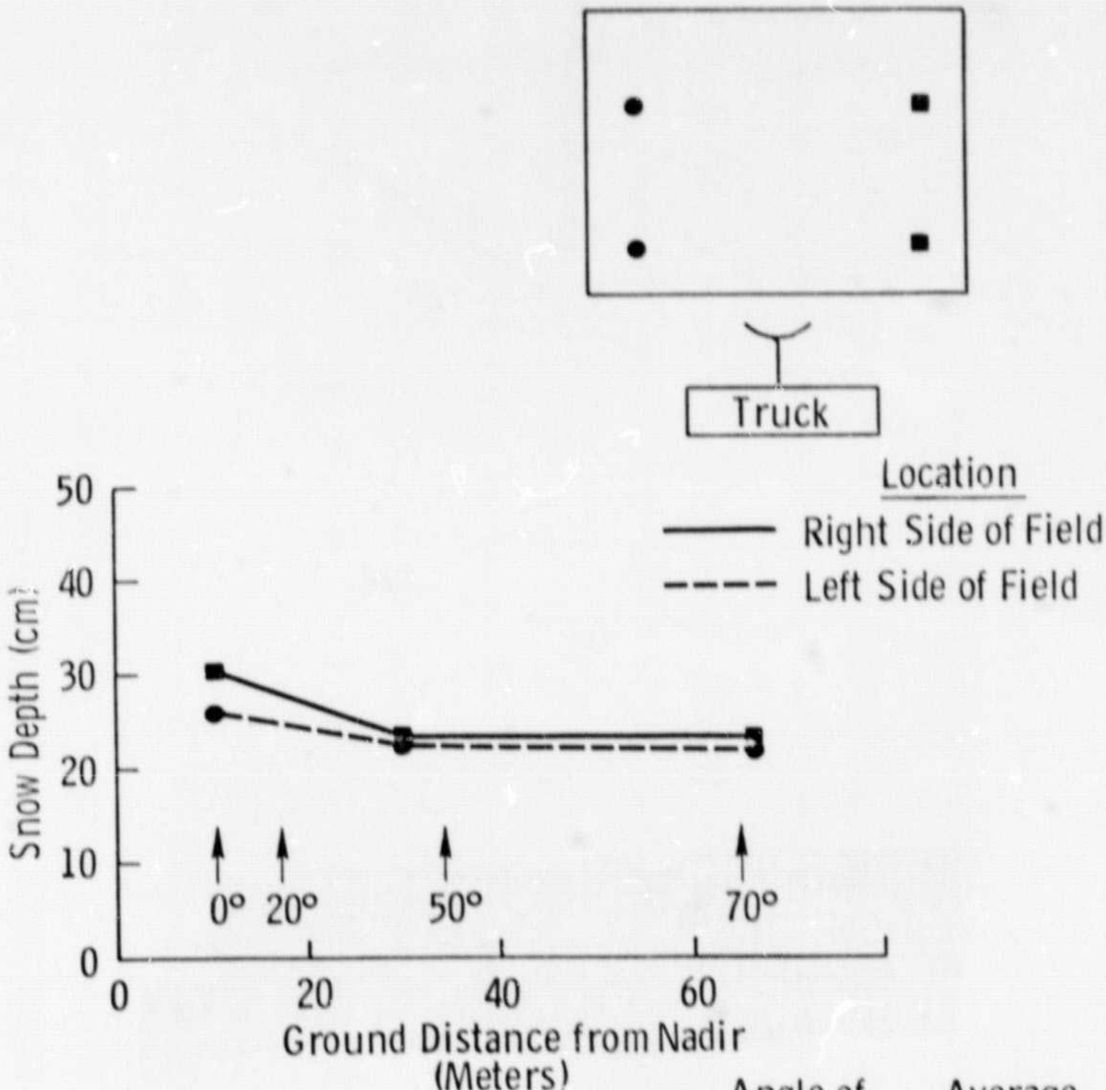
Figure 2.1. The MAS 8-18/35 system during data acquisition at the Staurolite snowdrift. The instrumentation van is pictured in the foreground and the hydraulic boom truck in the rear.

been harvested in the fall, the soil was turned over with a disc. The maximum-to-minimum height variation of the soil was of the order of 10 cm. Figure 2.2 shows the field after snowmelt; the trees in the foreground are approximately three feet tall. During data acquisition, the snow depth varied between 22 cm and 31 cm depending on spatial location, as shown in Figure 2.3. Figure 2.4 shows two photographs of the snow surface.

The second test site was an area of deep snow located behind the Staurolite Inn in Brookings. This area is pictured in Figure 2.5 and will henceforth be referred to as the "Staurolite snowdrift." The snowdrift formed as a result of the combined influences of the snowfence pictured in Figure 2.5b and the ridge next to the motel parking lot. These two obstructions caused snow to fill in between to a depth of approximately 80 cm. The snow-depth measurements are given in Figure 2.6. Although the depth varied significantly, it was fairly constant over the range of angles of incidence observed (40° and 50°). The far side of the fence also was observed at a 75° angle of incidence.

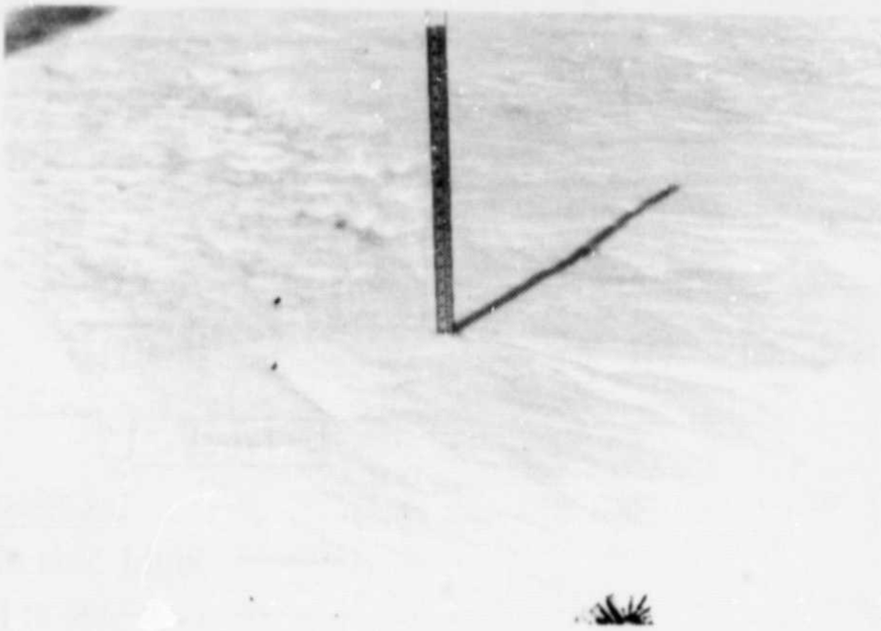
The third test site was the South Dakota State University (SDSU) football practice field (Figure 2.7). Visual observations suggested that the field was flat and that the snow depth was constant across the entire field. Snow depth measurements showed, however, that the soil surface was higher in elevation in the central part of the field than around the edges. Consequently, the snow depth was not the same for observations made at different angles of incidence; the depth was 70 cm for the 0°, 50 cm for the 20° and only 30 cm for the 50° and 70° angle of incidence data. The snow depths measured at this site are given in Figure 2.8.

Figure 2.2. Corn stubble field at SDSU Agricultural Engineering Research Unit

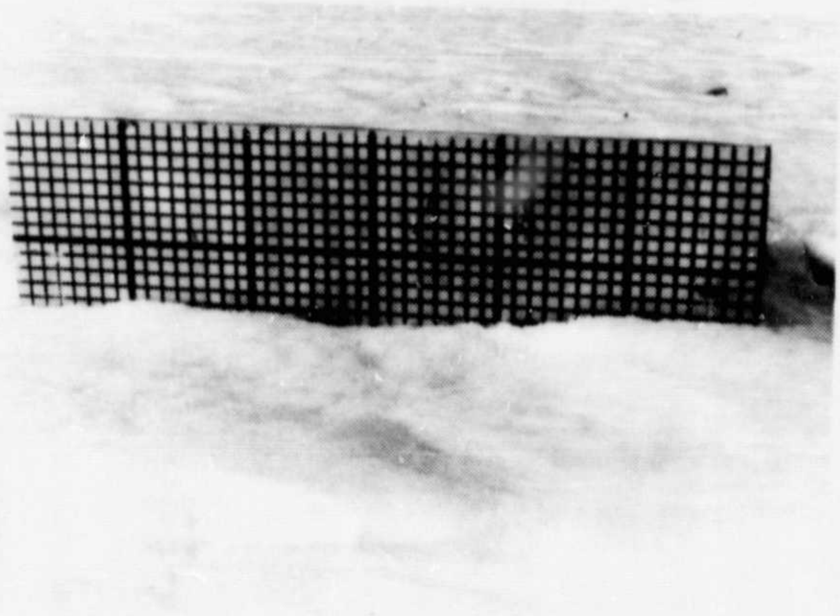


Angle of Incidence	Average Snow Depth
0°	28 cm
20°	26 cm
50°	23 cm
70°	23 cm

Figure 2.3. Snow depth of the corn-stubble field at the SDSU Agricultural Engineering Research Unit. These depths are valid for 3/12/79. The arrows indicate snow depths at the different angles of incidence.



(a)



(b)

Figure 2.4. Snow surface of the corn stubble field.

(a)

(b)

Figure 2.5. Photographs of the Staurolite snowdrift showing the MAS 8-18/35 boom and the snow fence.

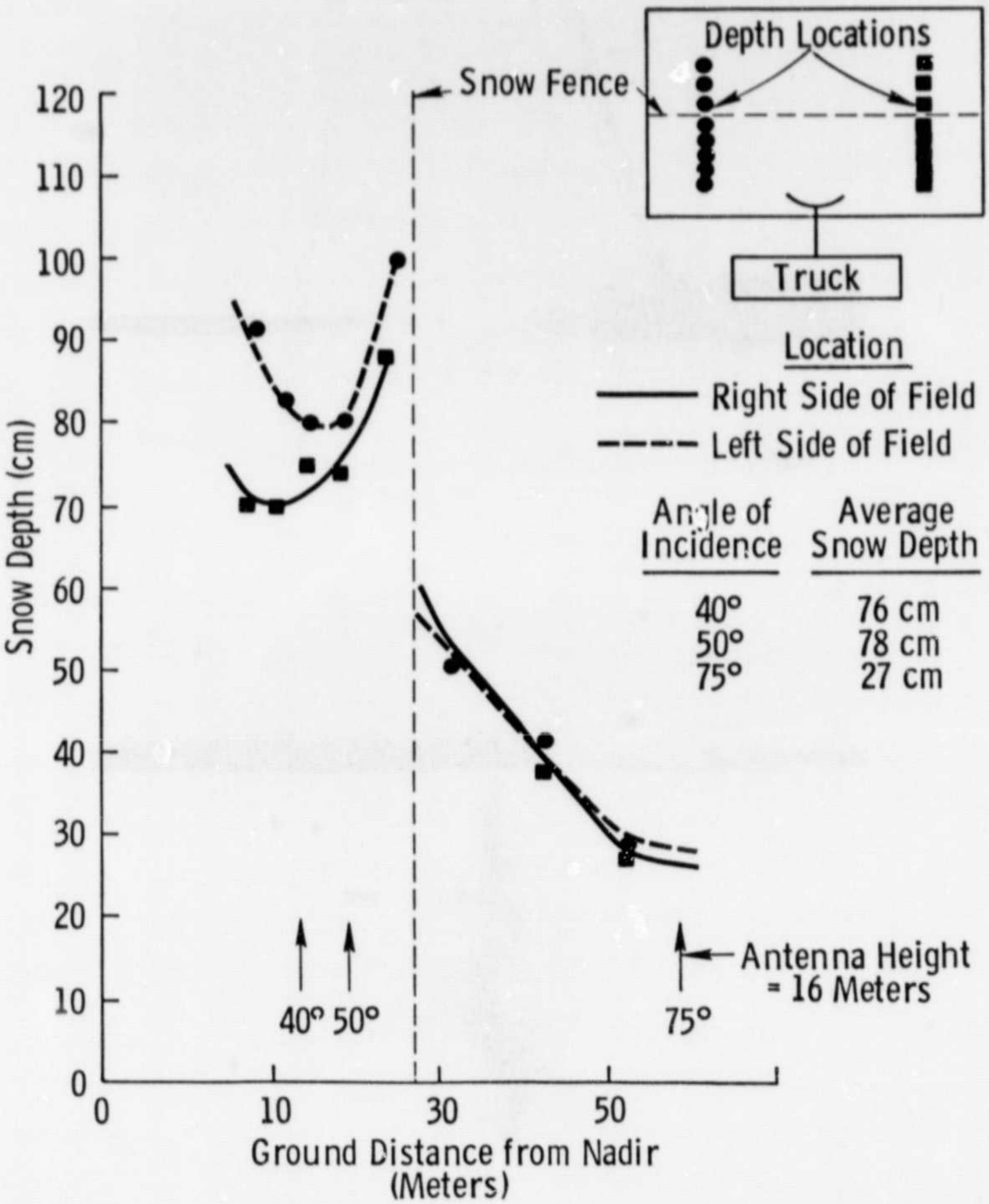


Figure 2.6. Snow depths of the snowdrift at the Staurolite Inn in Brookings, S.D. These depths are valid for 3/13 to 3/17/79. The arrows indicate snow depths at the different angles of incidence.

(a)

(b)

Figure 2.7. SDSU practice football field. (a) shows the MAS 8-18/35 boom shadow and the test-site surface and (b) shows a close-up of the snow surface.

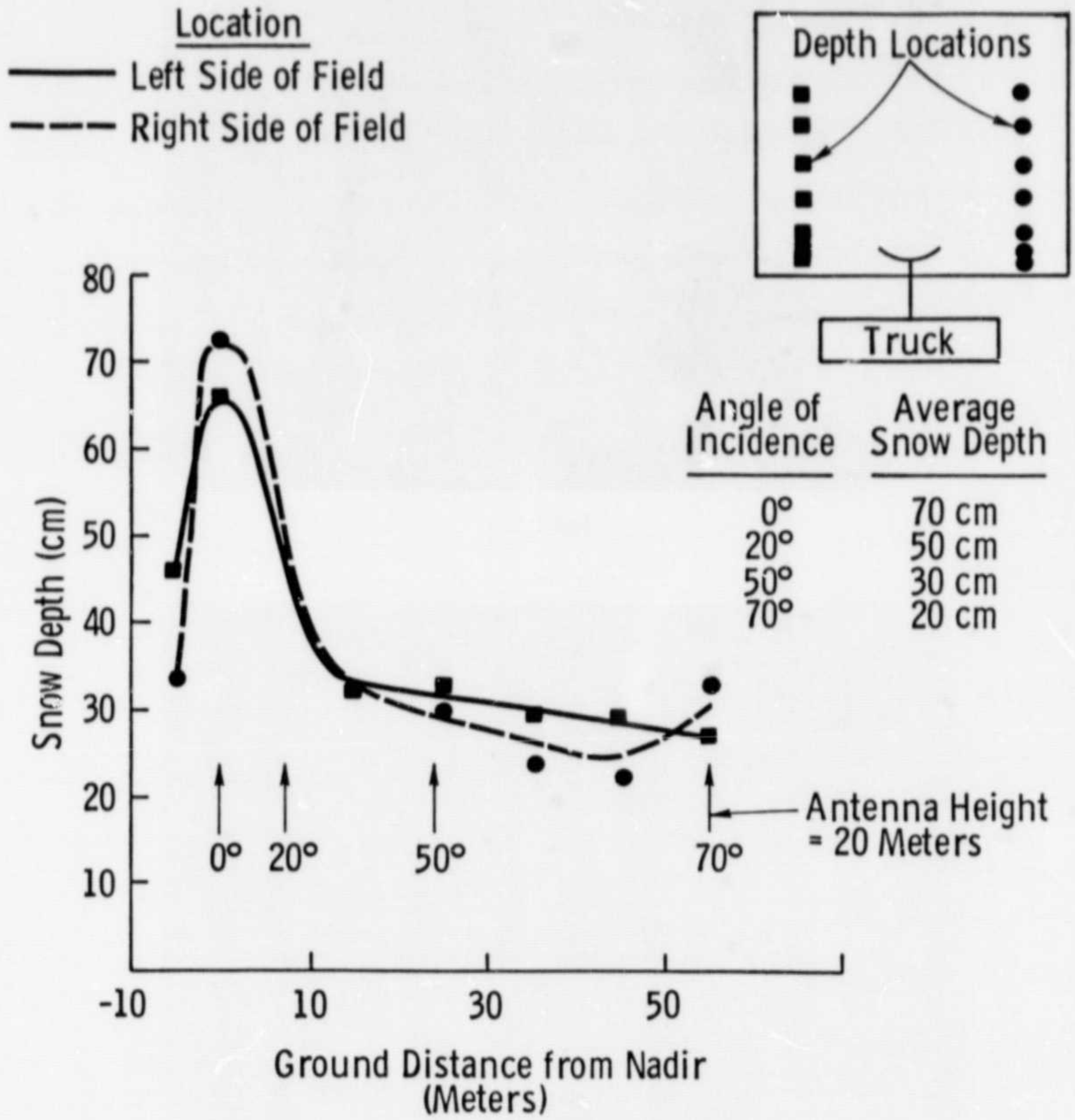


Figure 2.8. Snow depths at the SDSU football field. These depths are valid for both 3/14 and 3/16/79. The arrows indicate snow depths at the different angles of incidence.

2.2 MAS 8-18/35 Scatterometer

The MAS (Microwave Active Spectrometer) 8-18/35 is a truck-mounted wideband FM-CW radar; its system specifications are given in Table 2.1. A complete system description can be found in a report by Ulaby et al. (1979). Radar data were acquired at four frequencies (8.6, 13.0, 17.0 and 35.6 GHz) for two linear-polarization configurations (HH, horizontal transmit-horizontal receive and HV, horizontal transmit-vertical receive). These data were obtained at angles between 0° (nadir) and 75° angle of incidence.

The receive power levels were converted to scattering cross-section by a two-step calibration procedure. Short-term fluctuations, caused by oscillator power and other system variations, were removed by comparing the power received from the observation area to the power received through a delay line connected in lieu of the antennas. Calibration to absolute cross-section was achieved by referencing the received power from the target to the received power from an object of known radar cross-section. A Luneberg lens reflector was used for this purpose.

2.3 Ground Truth Description

The ground truth data consisted of the following: snow depth and stratification, snow water equivalent, snow wetness in the near-surface layers, snow surface roughness, temperature profiles and soil state. Stratification and density profiles, along with an overall water equivalent measurement, were obtained twice daily. The density samples were taken using a PVC cylinder with a volume of 105 ml. Usually, two

TABLE 2.1

MAS 8-18/35 System Specifications

	MAS 8-18	35 GHz Channel
Type	FM-CW	FM-CW
Modulating Waveform	Triangular	Triangular
Frequency Range	8-18 GHz	35.6 GHz
FM Sweep: ϕf	800 MHz	800 MHz
Transmitter Power	10 dBm	1 dBm
Intermediate Frequency	50 KHz	1.5 GHz & 50 KHz
IF Bandwidth	10 KHz	800 MHz & 10 KHz
Antennas:		
Height above ground	23 m	23 m
Type	46 cm Reflector	Scalar Horn
Feed	Quad-ridged Horn	---
Polarization	HH, HV, VV, RR, RL, LL	HH, HV, VV, RR, RL, LL
Beamwidths	4° at 8.6 GHz 2° at 17.0 GHz	3°
Incidence Angle	0° (nadir) - 80°	0° (nadir) - 80°
Calibration:		
Internal	Signal Injection (delay line)	Signal Injection (delay line)
External	Luneberg Lens Reflector	Luneberg Lens Reflector

to three cores were taken for a given layer. The overall water equivalent sample was taken vertically with a split-barrel PVC tube.

The liquid water in the surface layers (0-2 cm, 2-5 cm, and 5-10 cm) was measured using a freezing-calorimeter technique (Leaf, 1966; Stiles et al., 1977). The liquid water content is expressed as percent by volume (100 x gm/cm^3). The time interval for a single measurement was slightly less than 30 minutes. During periods of rapid change (snowmelt or freeze), the liquid water was sampled at this rate, while during periods of little change, it was sampled at approximately one-hour intervals. The surface roughness was recorded by photographing a metal plate with a one-inch grid (see Figure 3.10). In addition, temperature profiles were monitored at 30-minute time intervals using a digital thermometer. Finally, the soil state was checked daily to see if the ground was frozen or thawed. If the ground was thawed, the soil moisture was measured.

The ground-truth data are given in Appendix A. A more complete description of ground truth procedures and techniques is available in a previous report by Stiles and Ulaby (1980b).

2.4 Data Acquisition

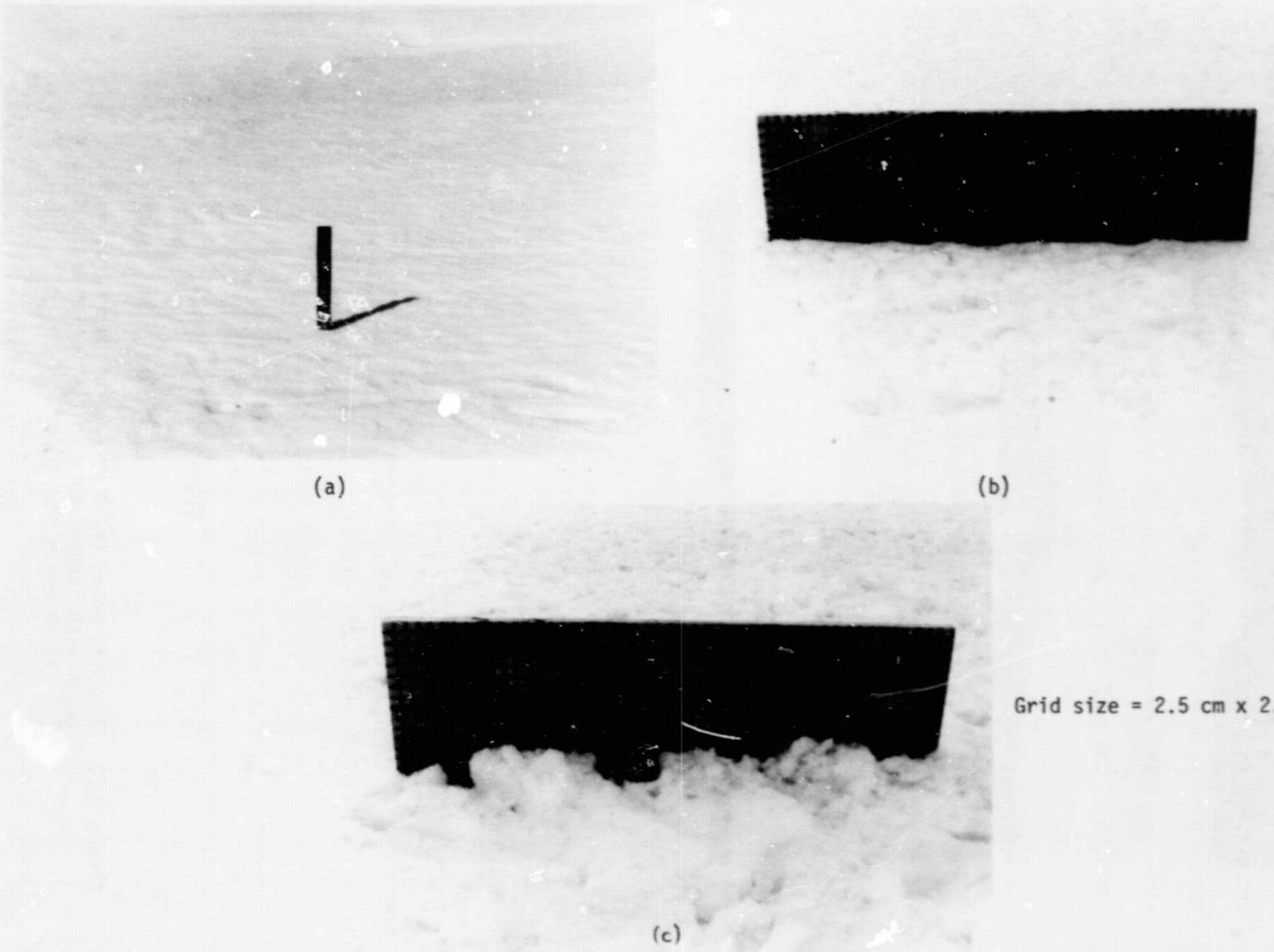
Data were acquired over an eight-day period. On six of those days, data were obtained continuously for periods of from 9 to 14 hours. Generally, three angles of incidence were monitored per data-set, resulting in data-set durations of approximately 40 minutes each.

During these diurnal experiments, dry snow conditions were observed for three days, wet snow was observed for one day, and the snowmelt

process was observed during two of the days. Weather conditions prevented observation of the snowmelt process at the Staurolite snowdrift site, while the other targets were observed under these conditions. Analysis of these observations is given in Section 3.1.

The effects of surface roughness on σ^0 were investigated for one day under wet snow conditions. The roughness was produced in three stages. First, the σ^0 behavior of the natural snow surface (smooth) was measured. Then the experiment-personnel walked over the area, creating footprint impressions to a depth of about three inches, thereby generating a "rough" surface. Finally, walking on and kicking the snow created a "very rough" surface characterized by many footprints and "clods" or balls of snow. These surfaces are pictured in Figure 2.9. Again, weather conditions prevented observations over dry snow. Analysis of these data is presented in Section 3.2.

On the final day of observations, a snowpile experiment was conducted. The Staurolite snowdrift area was cleared or piled, as required, to the following snow-depths: 0 cm (bare), 51 cm, 79 cm (natural depth), and 143 cm. These areas are pictured in Figure 2.10. Standard multiparameter data sets were obtained. In another format, frequency, angle, and polarization were fixed and the antennas were scanned across the four test-piles. The received power was recorded on an X-Y plotter. The snowpile measurements were made at 0° (nadir) and 40° angle of incidence for HH and HV polarizations. Analysis of the scan as well as regular data for the snowpiles is given in Section 3.3.



(a) (b) (c)

Grid size = 2.5 cm x 2.5 cm

Figure 2.9. The effect of varying roughness of wet snow, (a) smooth surface, (b) rough surface, (c) very rough surface.

(a)

(b)

Figure 2.10. Snowpile areas (a) 0 cm - bare ground (b) 59-cm depth with natural snow in the foreground and (c) 143 cm depth snow pile.

(c)

3.0 DATA ANALYSES

This section presents the data analyses for the Brookings experiment and compares these results with the Colorado observations made in 1977.

3.1 Diurnal Response

Diurnal experiments were performed at least once at each of the test sites. One diurnal set was obtained on the corn-stubble field; two were obtained from the football field; and three were obtained from the Staurolite snowdrift.

3.1.1 Snowcovered Corn-Stubble

The snowcovered corn-stubble field is pictured in Figures 2.2 and 2.4. It was observed only once, on March 12, 1979, because complete snowmelt occurred before the field could be visited again. Figure 3.1 illustrates the temperature variation and the snow liquid water variation as a function of time. The sky conditions remained clear, with the air temperature staying below 0° C most of the day. A peak temperature of 0.5° C was observed in the afternoon. With this positive temperature, and negligible winds, a peak liquid water content of about 4% by volume was measured in the surface snow layer (0-2 cm). This value decreased later in the afternoon, due to a decrease in solar intensity and air temperature. The ground remained frozen all day. Figure 2.3 shows the snow depths measured for this field at different locations. At nadir and low angles of incidence, the snow was an average of 28 cm deep. For high angles of incidence, the depth decreased slightly to an average of 22 cm.

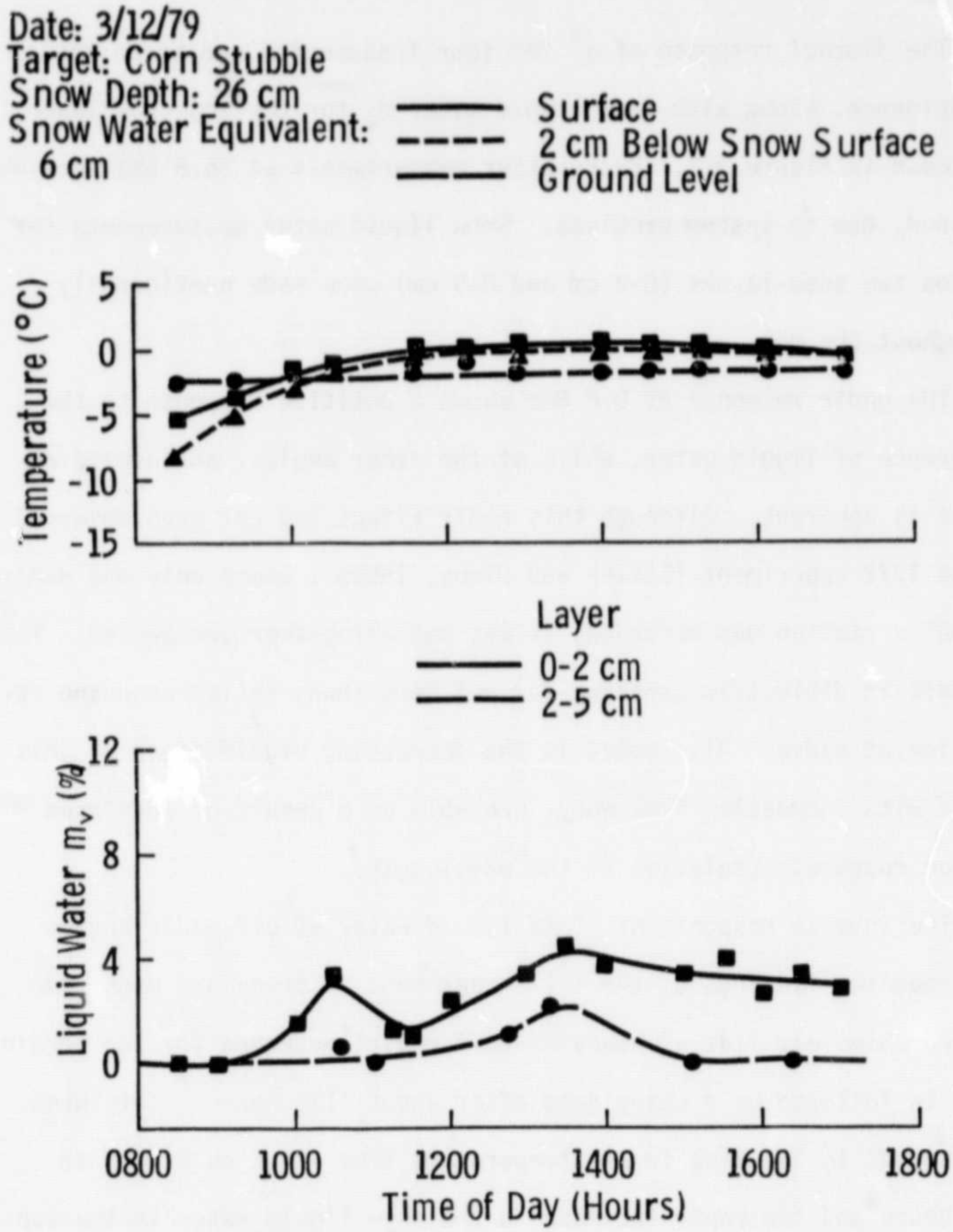
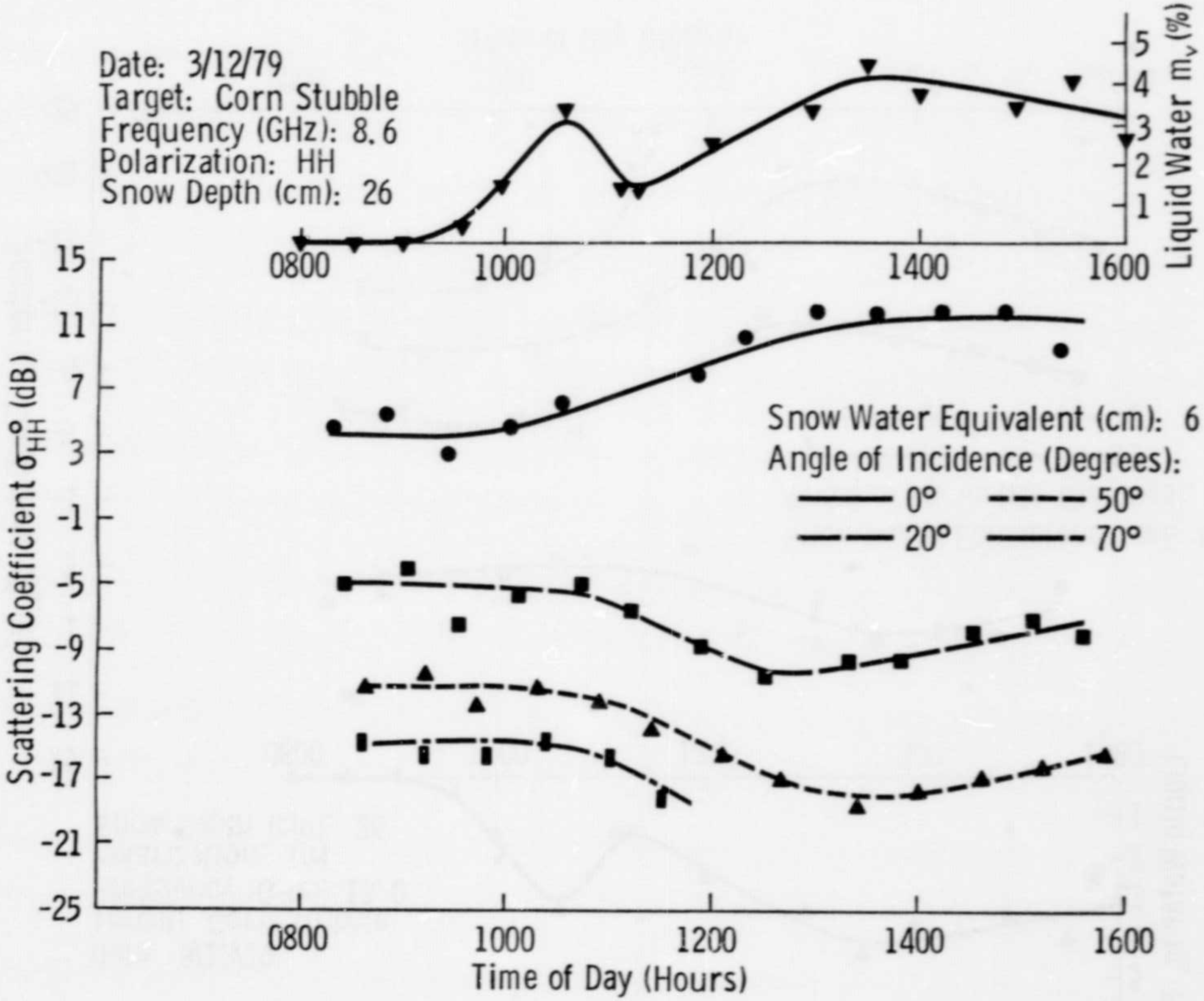


Figure 3.1. Temperature and liquid water variation on the corn stubble.

The diurnal response of σ^o for four frequencies and three angles of incidence, along with snow liquid water m_v for the top snow layer, are shown in Figure 3.2. Backscatter measurements at 35.6 GHz were not obtained, due to system problems. Snow liquid water measurements for the top two snow-layers (0-2 cm and 2-5 cm) were made continuously throughout the day.

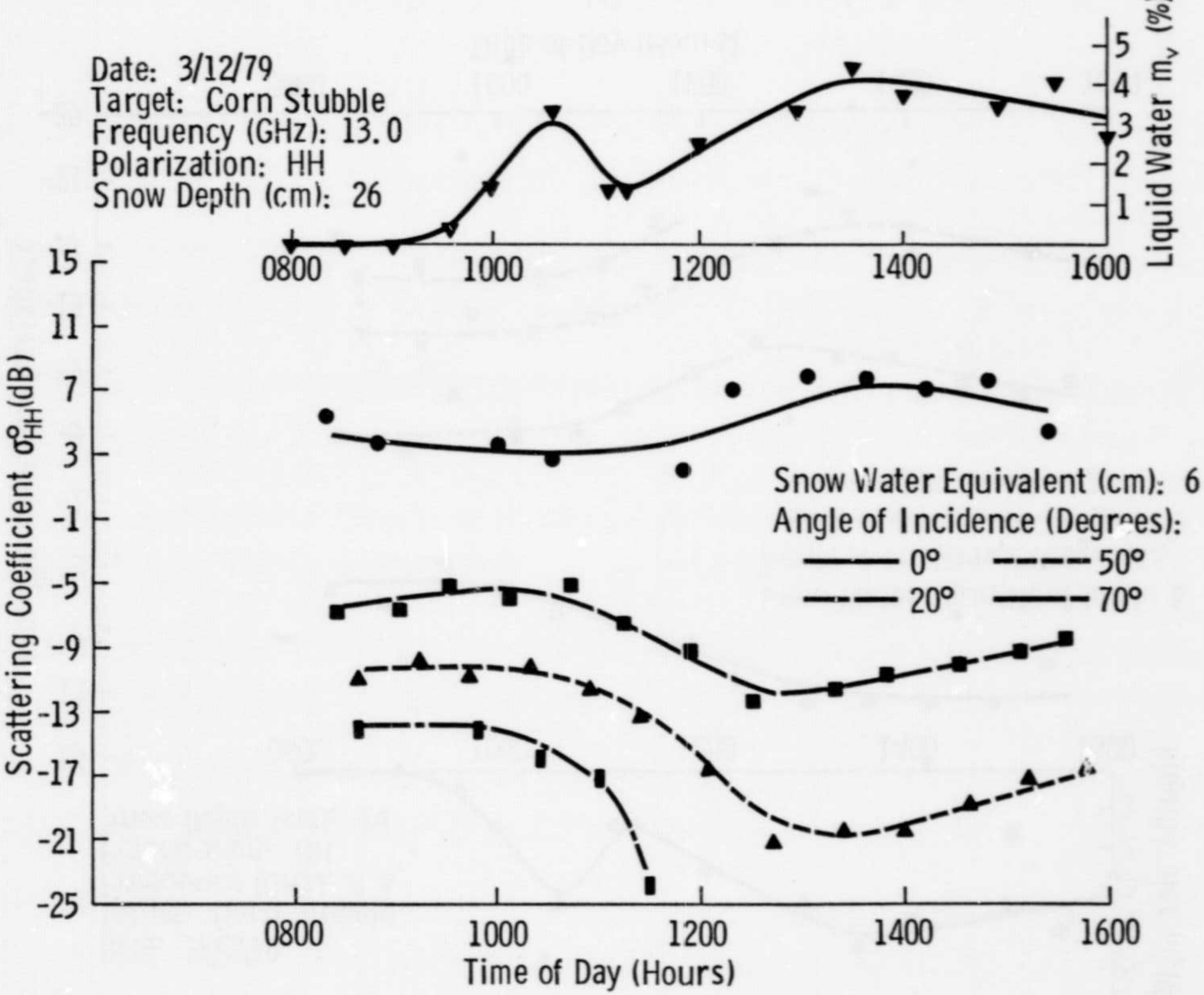
The nadir response at 8.6 GHz shows a positive response to the appearance of liquid water, while at the other angles, an inverse response is apparent. Although this nadir effect had not been observed in the 1977 experiment (Stiles and Ulaby, 1980b), where only one nadir diurnal variation was recorded, it was not altogether unexpected. The increase in dielectric constant for wet snow tends to increase the reflection at nadir. Also noted is the decreasing significance of this effect with increasing frequency, probably as a result of increased surface roughness (relative to the wavelength).

The inverse response of σ^o to liquid water at off-nadir angles confirmed the findings of the 1977 experiment in trend and magnitude. The approximately flat σ^o behavior (off-nadir) observed for the morning hours is followed by a sharp drop after about 1130 hours. This drop corresponds to the rise in air temperature from -1° C to 0.2° C at 1130 hours and the rapid increase in the snow liquid water in the topmost snow-layers. The magnitude of the change in σ^o values is at first surprising. One might not expect a significant amount of liquid water to be formed for air temperatures just a fraction above 0° C. The clear skies and calm winds, however, allowed a large amount of solar energy to be transferred to the snow, resulting in the snowmelt. From this

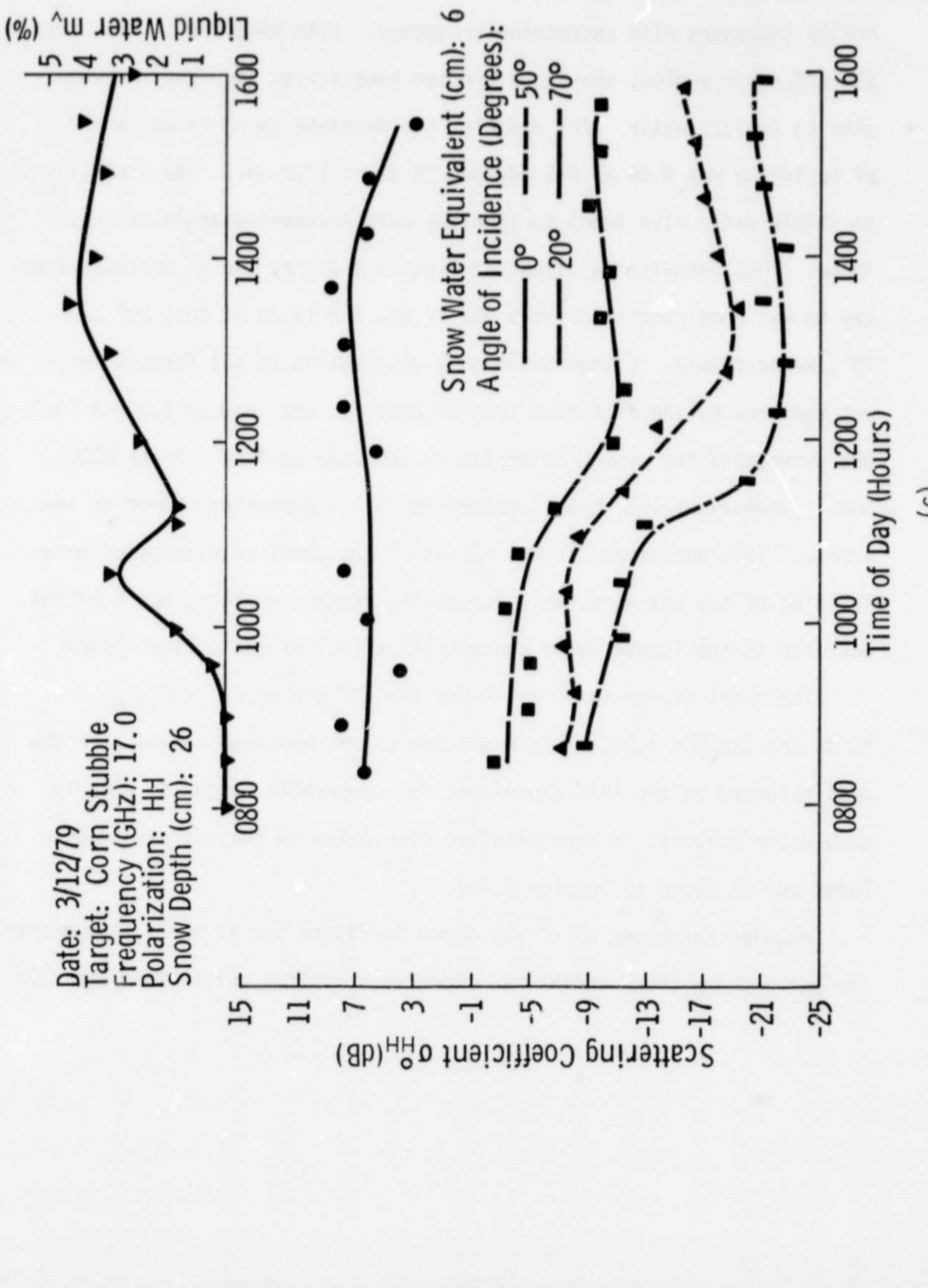


(a)

Figure 3.2. Diurnal variation of m_v and σ^o at (a) 8.6 GHz, (b) 13.0 GHz, and 17.0 GHz on the corn stubble.


Date: 3/12/79
Target: Corn Stubble
Frequency (GHz): 13.0
Polarization: HH
Snow Depth (cm): 26
Liquid Water m_v (%)
Scattering Coefficient σ^o_{HH}(dB)
Snow Water Equivalent (cm): 6
Angle of Incidence (Degrees):
0°
50°
20°
70°
Time of Day (Hours)

(b)


Date: 3/12/79
Target: Corn Stubble
Frequency (GHz): 17.0
Polarization: HH
Snow Depth (cm): 26
Snow Water Equivalent (cm): 6
Angle of Incidence (Degrees):
0°
20°
50°
70°
Liquid Water m_v (%)
5
4
3
2
1
Scattering Coefficient σ^o_{HH}(dB)
15
11
7
3
-1
-5
-9
-13
-17
-21
-25
0800
1000
1200
1400
1600
Time of Day (Hours)

(c)

diurnal set, we can observe that air temperatures alone are of little help in determining the wetness of or microwave response to snow. Also noted is that the decrease in σ^o in response to snow liquid water generally increases with increasing frequency. This behavior is true for all off-nadir angles, showing a greater sensitivity at higher frequencies to surface water. For example, the decrease in σ^o at 50° angle of incidence was 6 dB at 8.6 GHz and 10 dB at 17.0 GHz. The sensitivity to liquid water also tends to increase with increasing angle of incidence. This behavior is illustrated at 17.0 GHz by the σ^o decrease from dry to wet snow conditions of 8 dB, 12 dB, and 13 dB at 20°, 50° and 70°, respectively. Extension of this observation to all frequencies was hampered by the fact that the 70° data for wet snow at 8.6 and 13.0 GHz approached the system noise limits and were omitted. After 1300 hours (approximately), the σ^o values for all frequencies showed an increase. This phenomenon is the result of the combined effects of uneven settling of the wet snow, which created a rougher surface, and a slight decrease in the liquid water content (4% to 3%) of the surface layer.

The total change in σ^o at 17 GHz for 50° and m_v is $|\Delta\sigma^o_{17.0}| =$ 12 dB and $|\Delta m_v| = 4.5\%$. This magnitude of the response agrees with the data gathered in the 1977 experiment for comparable change in snow liquid water content. A more detailed discussion of the response magnitudes can be found in Section 3.4.1.

Angular responses of σ^o are shown in Figure 3.3 at three frequencies for wet and dry snow conditions, along with typical curves from the 1977

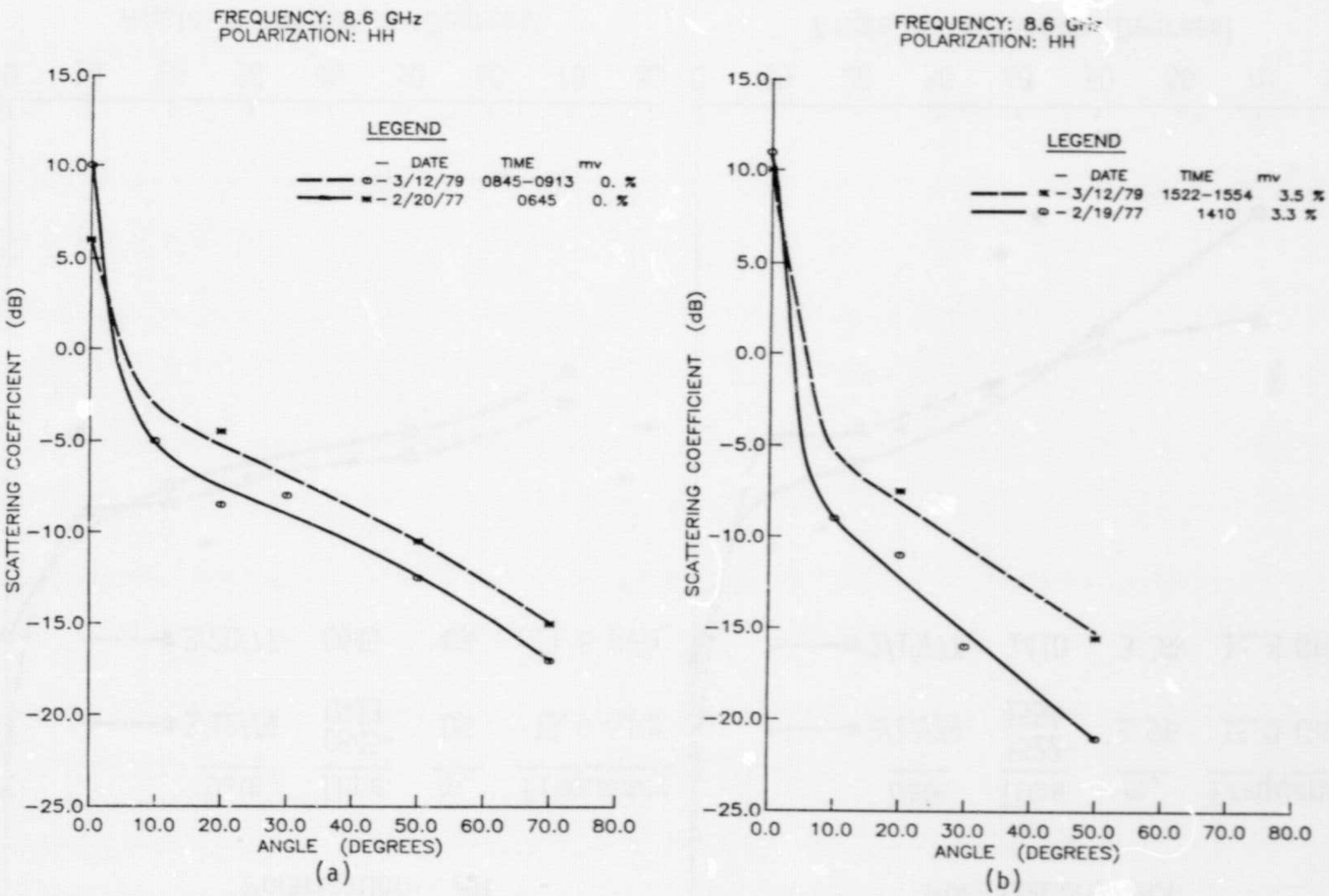
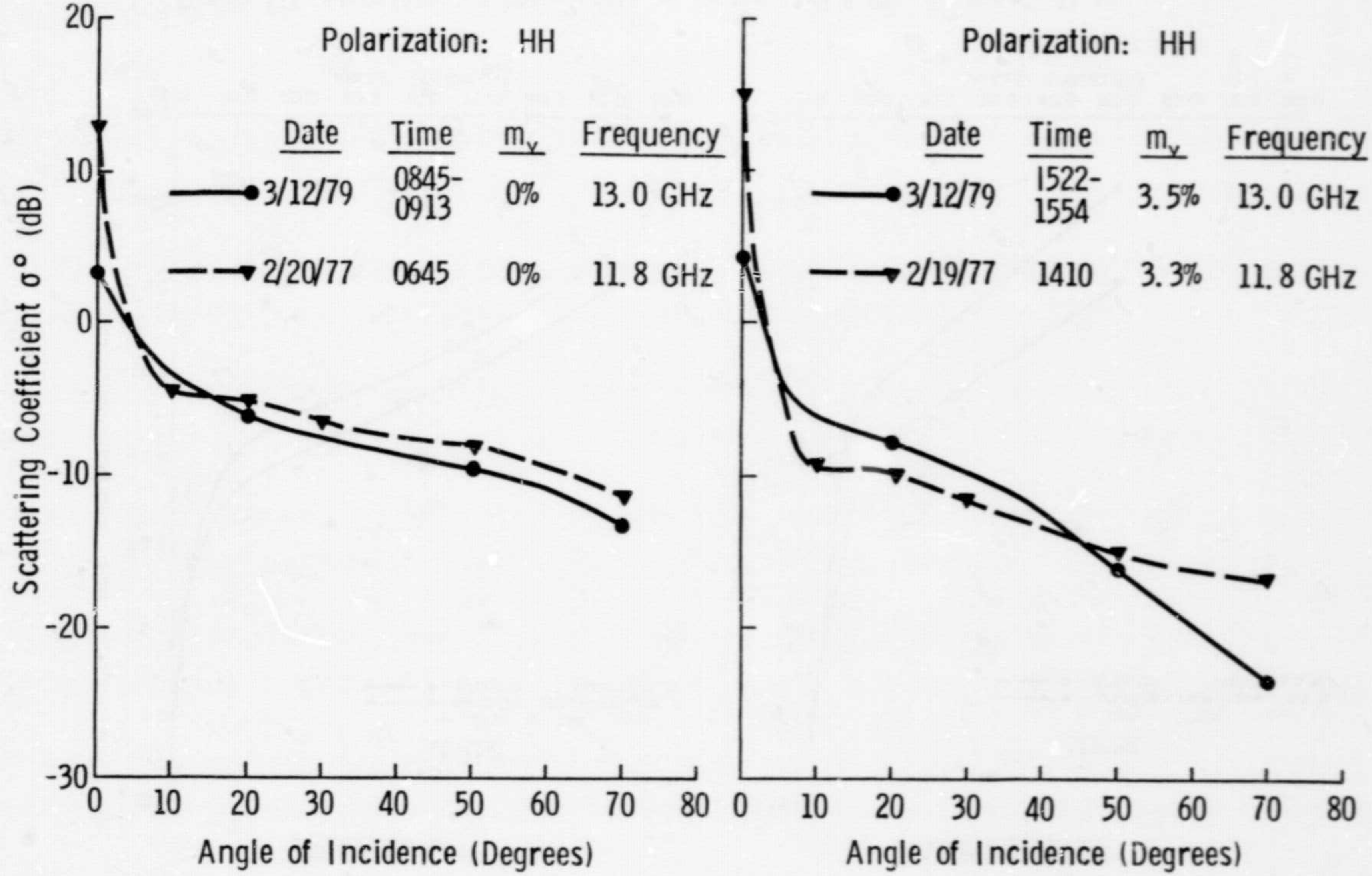
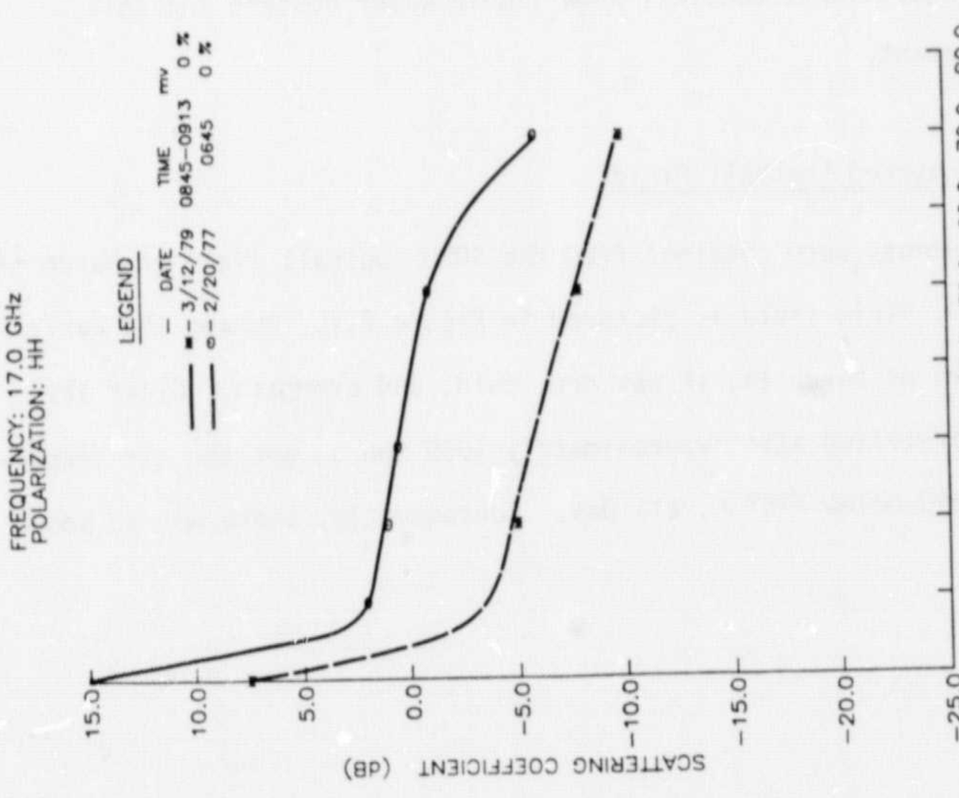


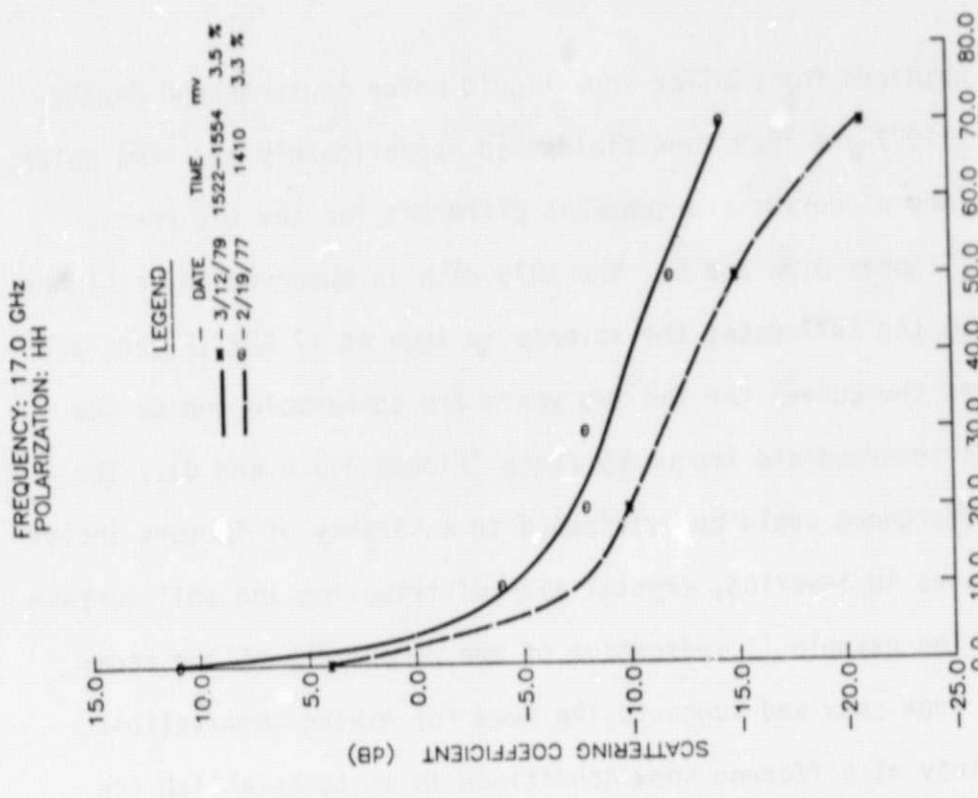
Figure 3.3 Comparison of the σ^{o} data at (a and b) 8.6 GHz, (c and d) 11 to 13 GHz, and (e and f) 17.0 GHz from two different years and climatic conditions for wet and dry snow conditions.


Polarization: HH
Date
Time
m_v
Frequency
3/12/79
0845-0913
0%
13.0 GHz
2/20/77
0645
0%
11.8 GHz
Polarization: HH
Date
Time
m_v
Frequency
3/12/79
1522-1554
3.5%
13.0 GHz
2/19/77
1410
3.3%
11.8 GHz
Scattering Coefficient σ° (dB)
20
10
0
-10
-20
-30
0
10
20
30
40
50
60
70
80
Angle of Incidence (Degrees)
Angle of Incidence (Degrees)

(c) (d)


FREQUENCY: 17.0 GHz
POLARIZATION: HH
LEGEND
— DATE TIME mv
■ – 3/12/79 0845–0913 0 %
● – 2/20/77 0645 0 %
SCATTERING COEFFICIENT (dB)
15.0
10.0
5.0
0.0
−5.0
−10.0
−15.0
−20.0
−25.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
ANGLE (DEGREES)

(e)


FREQUENCY: 17.0 GHz
POLARIZATION: HH
LEGEND
— DATE TIME mv
■ – 3/12/79 1522–1554 3.5 %
● – 2/19/77 1410 3.3 %
SCATTERING COEFFICIENT (dB)
15.0
10.0
5.0
0.0
−5.0
−10.0
−15.0
−20.0
−25.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
ANGLE (DEGREES)

(f)

experiment obtained for similar snow liquid water contents and depths. Although the 1977 and 1979 snow fields had approximately the same water equivalent, the σ^{o} curves are somewhat different for the two years. At 8.6 GHz (Figures 3.3a and b), the 1979 data is observed to be higher in level than the 1977 data; the reverse is true at 17 GHz (Figure 3.3 e and f), and the curves for the two years are comparable one to the other in the intermediate frequency range (Figure 3.3 c and d). The observed differences could be attributed to a variety of factors including differences in layering, crystal size distribution and soil surface roughness. The example is indicative of the complexity of the radar backscatter from snow and suggests the need for making observations under a variety of different snow conditions so as to establish the statistical variability associated with changes in parameters other than water equivalent, density, snow liquid water content and soil moisture content.

3.1.2 Snowcovered Football Field

Measurements were obtained from the SDSU football field on March 14 and 16, 1979. This field is pictured in Figure 2.7. During the early morning hours of March 14, it was dry, cold, and overcast. Clear sky conditions prevailed after approximately 1030 hours, but the air temperature remained below -10° C, all day. Consequently, there was no snow-

melt. This particular weather condition had not been observed previously and it demonstrated that the air temperature must be close to 0° C for snowmelt to occur in the very-near-surface layer. The ground was frozen at the high angle of incidence target areas (50° and 70°), where the snow depth was about 30 cm. It was thawed at the near-nadir area, where the 70-cm snow depth had insulated the soil from the cold air during the previous night. The temperature variation at the soil surface. snow surface, and for the air approximately one meter above the soil surface is shown in Figure 3.4 for both days. Also shown is the liquid water content, m_v, for the 0-2 and 2-5 cm snow layers. Since there was no snowmelt on March 14, the σ^o response was flat for all frequencies and angles of incidence away from nadir. Figure 3.5 depicts the diurnal response at 17 GHz, and Figure 3.6 shows the response at 50° angle of incidence for two days of observation. The combination of the "unchanging" snow conditions and the "perfectly stable" scatterometer provides an opportunity to evaluate the variance under supposedly constant conditions. Table 3.1 presents the mean and standard-deviation values expressed in dB units. With few exceptions, the standard deviation is less than 1.3 dB for both polarizations at all frequencies. These values are much smaller than variations which result when snowpack characteristics change. Also, the mean σ^o values at the 50° and 70° angles for this day were observed to increase with increasing frequency. This trend is in agreement with the results of past experiments (Stiles and Ulaby, 1980).

The second diurnal experiment on this field was performed on March 16, 1979. Sunny skies during the early morning turned cloudy around 0900

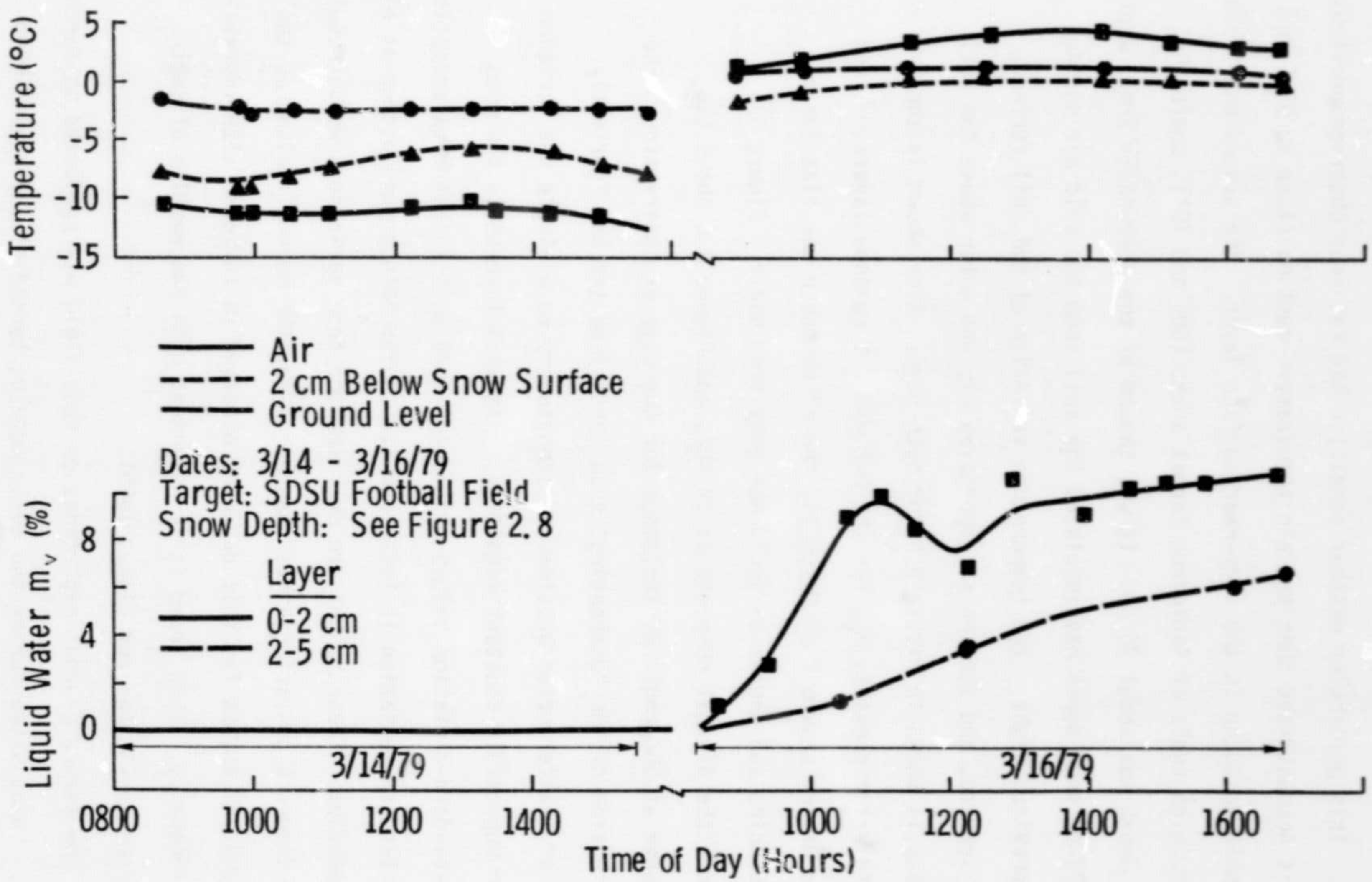


Figure 3.4. Temperature and liquid water variation for the two days' observations on the SDSU football field.

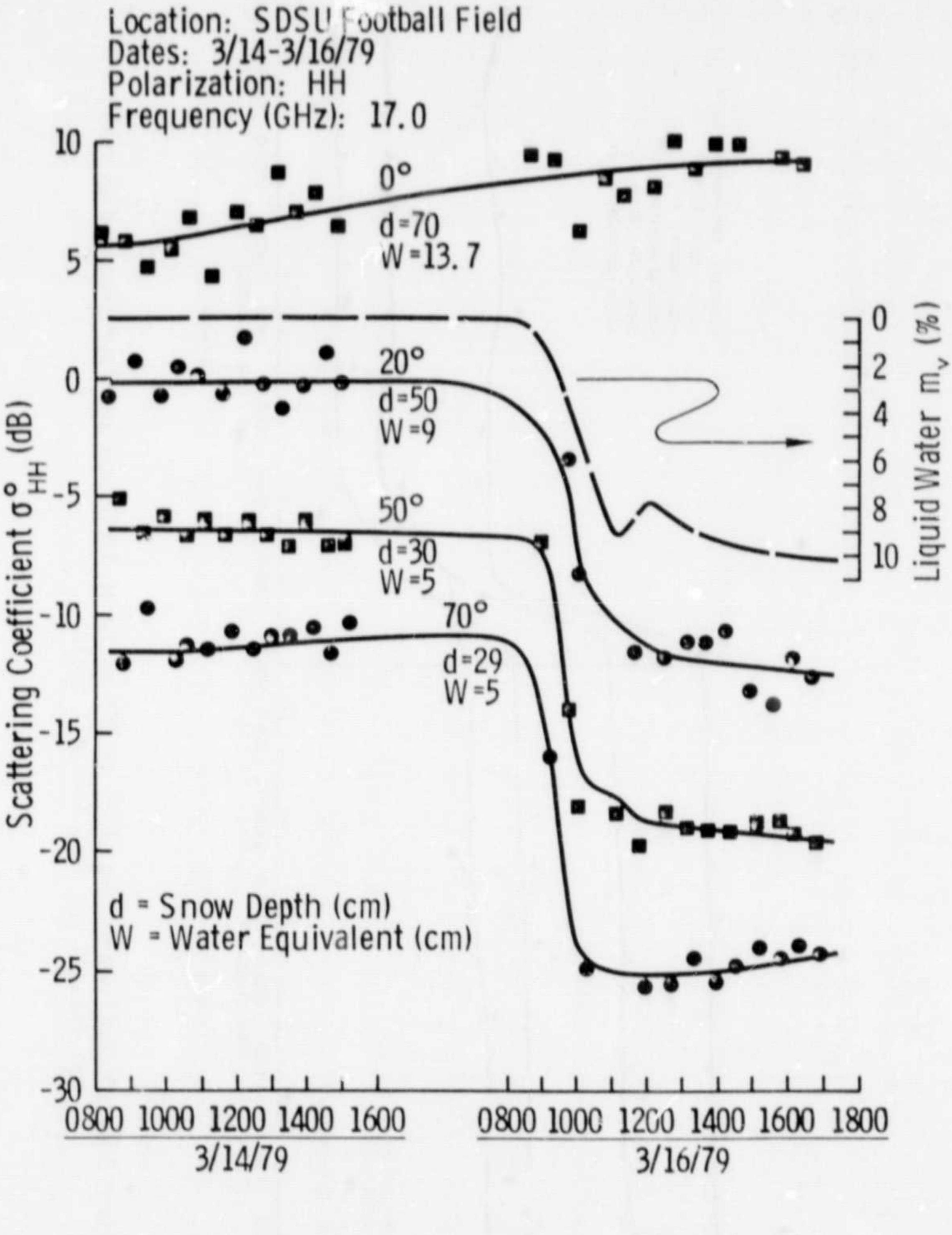


Figure 3.5. Diurnal variation at m_v and σ^o at 17 GHz and four angles of incidence over two days on the SDSU football field.

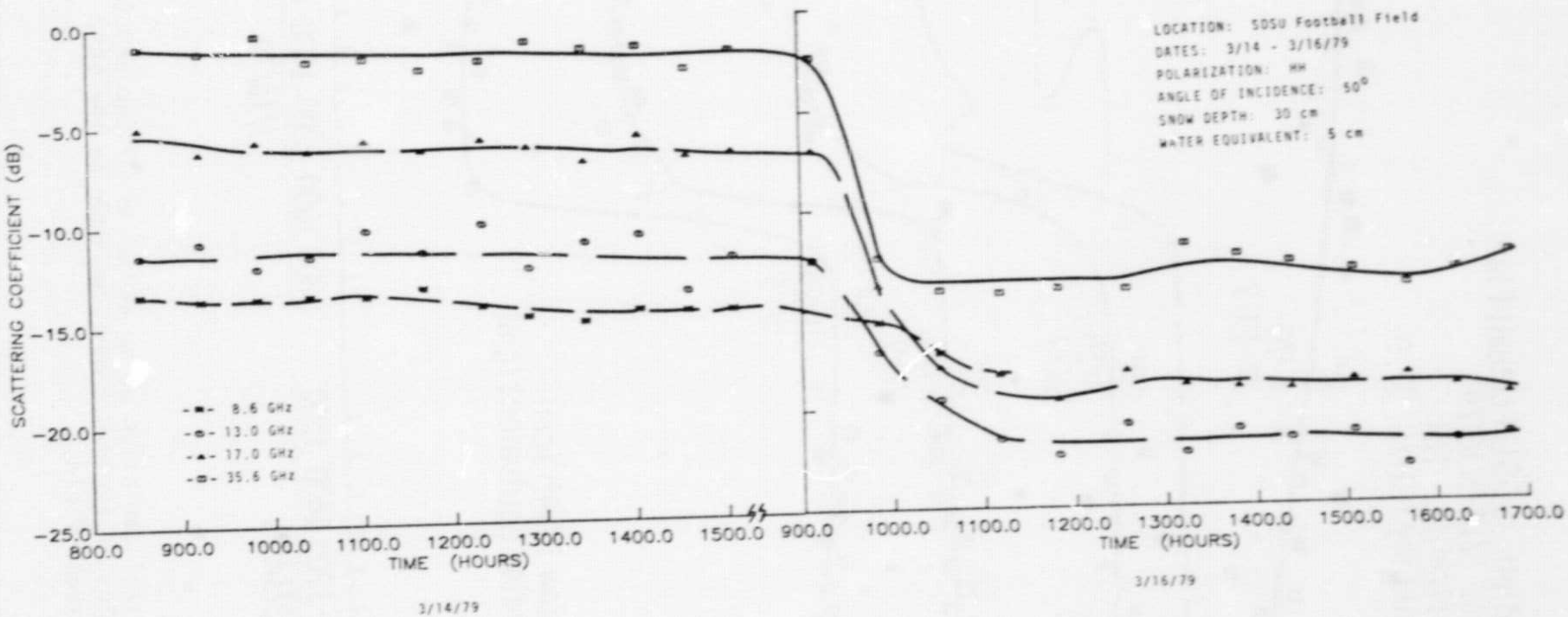


Figure 3.6. Diurnal variation of σ^0 at 50° angle of incidence and four frequencies over two days on the SDSU football field.

TABLE 3.1

COMBINED MAS SYSTEM AND SNOW VARIATION UNDER "CONSTANT" CONDITIONS ON 3/14/79

(Liquid Water Content m_v = 0%)

Mean σ^o (dB)					
Angle of Incidence (degrees)	Polarization	Frequency (GHz)			
		8.6	13.0	17.0	35.6
0°	HH	7.85	4.06	6.42	5.6
	HV	1.01	- 3.83	- 1.03	-4.54
20°	HH	0.48	- 1.2	- 0.06	-0.81
	HV	- 3.96	- 7.4	- 6.26	-4.35
50°	HH	-14.09	-11.49	- 6.2	-1.55
	HV	-20.31	-16.86	-11.96	-4.93
70°	HH	---	-16.69	-10.98	-8.09
	HV	-25.15	-22.69	-17.28	---

Standard Deviations of σ^o (dB)					
Angle of Incidence (degrees)	Polarization	Frequency (GHz)			
		8.6	13.0	17.0	35.6
0°	HH	0.91	1.37	1.27	0.73
	HV	0.9	1.28	0.8	0.87
20°	HH	0.53	1.3	0.87	0.58
	HV	1.01	1.76	0.67	0.67
50°	HH	0.61	0.97	0.55	0.58
	HV	0.55	0.88	0.68	0.77
70°	HH	---	1.05	0.7	1.17
	HV	0.44	0.61	1.36	---

hours. The air temperature was at 1° C at 0900 and continued to rise in a warming trend that peaked at about 5° C at 1400 hours. Snow liquid water values of almost 3% by volume were observed as early as 0900 and increased to more than 10% during the afternoon (Figure 3.4).

Figures 3.5 and 3.6 show the diurnal variation of σ^o. Again σ^o is observed to decrease with m_v, and the magnitude of its sensitivity to m_v, $|\partial\sigma^o/\partial m_v|$, appears to increase with increasing angle of incidence and frequency. At 17 GHz (Figure 3.5) the change in σ^o between noon on 3/14 and noon on 3/16 is about 10 dB at $\theta = 20°$, increasing to 14 dB at $\theta = 70°$. Figure 3.6 provides a comparison of different frequencies, all at $\theta = 50°$. The 8.6 GHz curve is incomplete due to system noise problems at that frequency. For the other frequencies, the change in level of σ^o between the two days increases from about 11 dB at 13 GHz to 13 dB at 35 GHz.

Further comparisons of dry and wet snow conditions are shown in Figure 3.7 for four different frequencies. In each case, the dry snow curve represents an average of the dry snow data acquired on 3/14/79 (see Table 3.1 for standard deviation), and the wet snow curve represents an average of data sets acquired on 3/16/79 for which $m_v = 10 \pm 2\%$.

3.1.3 Staurolite Snowdrift

Figure 2.5 shows the snowdrift behind the Staurolite Inn. Data at four frequencies and three angles, 40°, 50° and 75°, were taken over a three-day period. Graphs showing temperature variation for the three days appear in Figure 3.8.

The first day, March 13, 1979, had clear weather conditions, with air temperatures below -6° C. The ground was frozen down to 5 cm with completely dry snow on top. The unvarying conditions provided another chance to check the stability of the measurement system. Table 3.2 shows

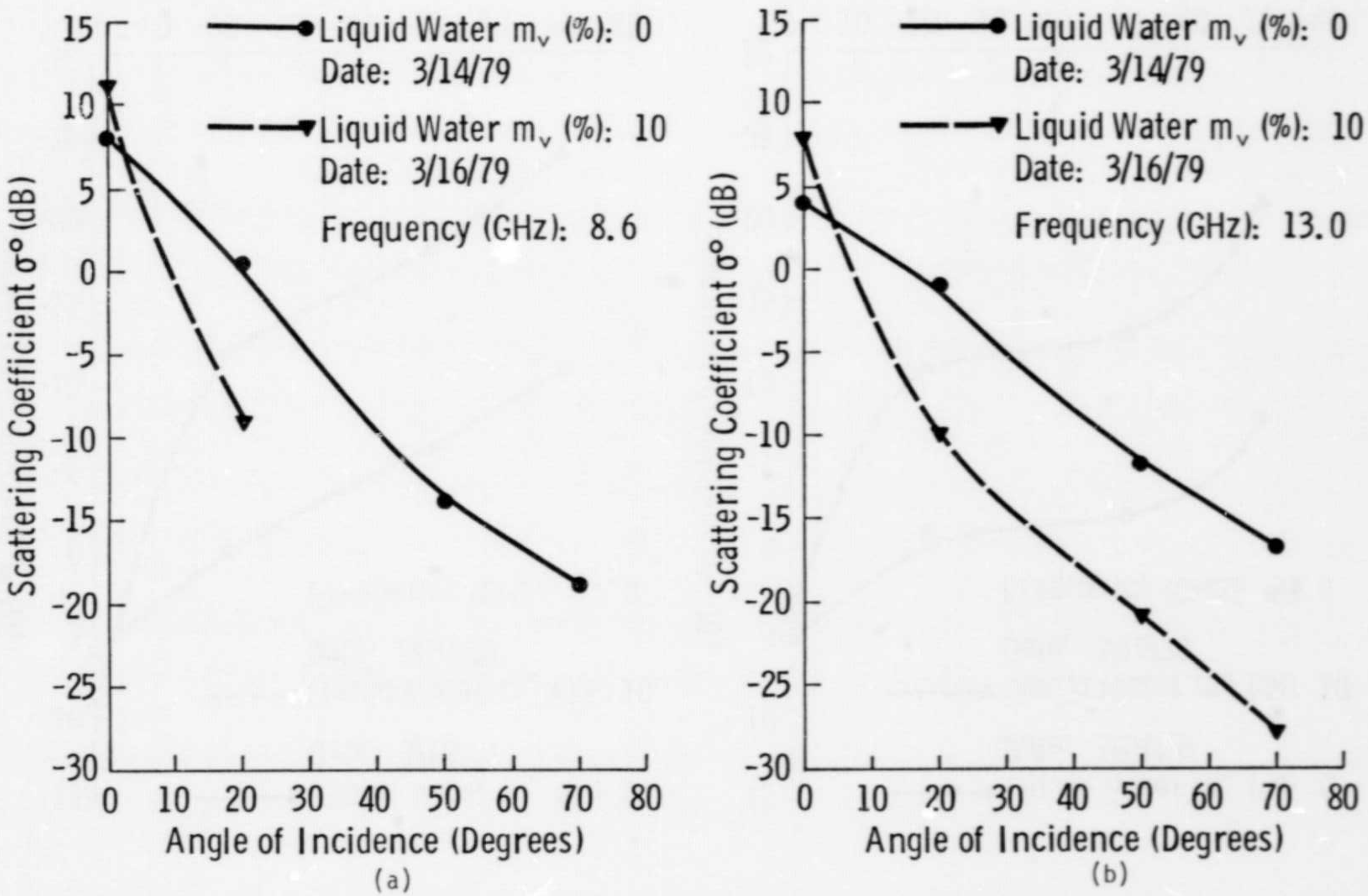
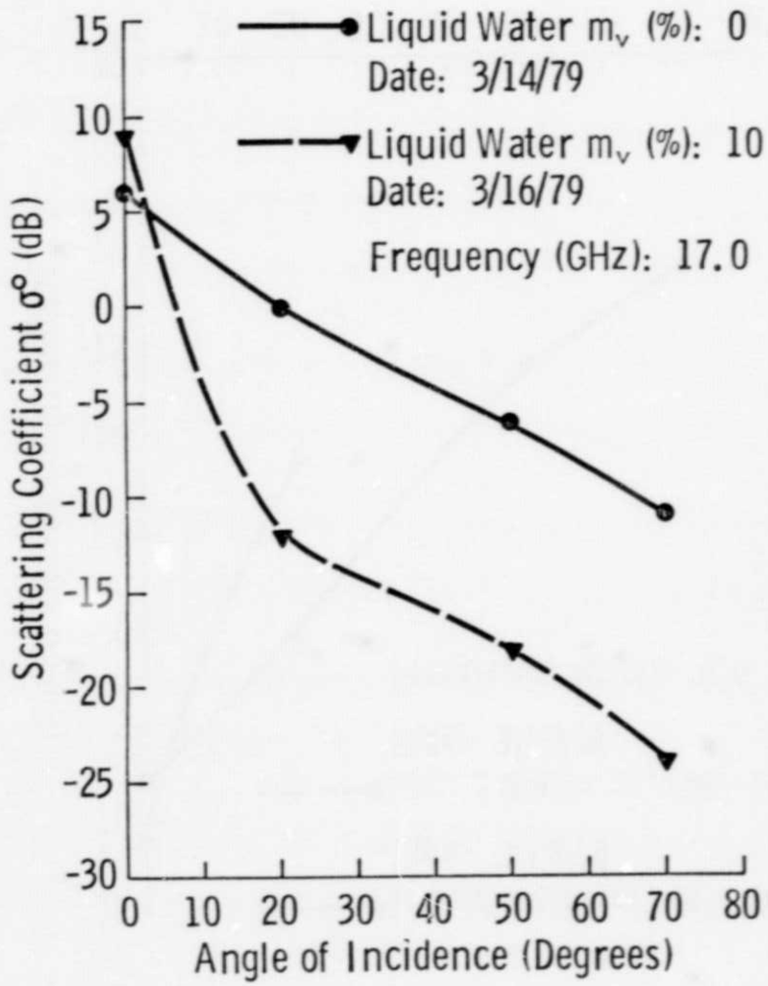
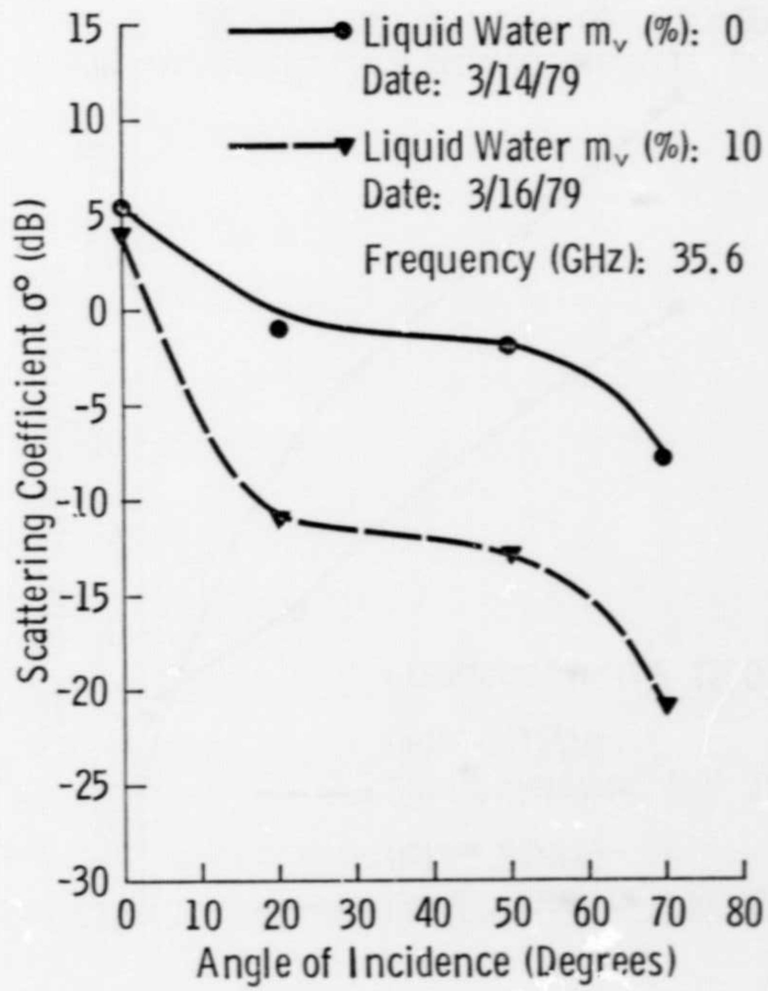


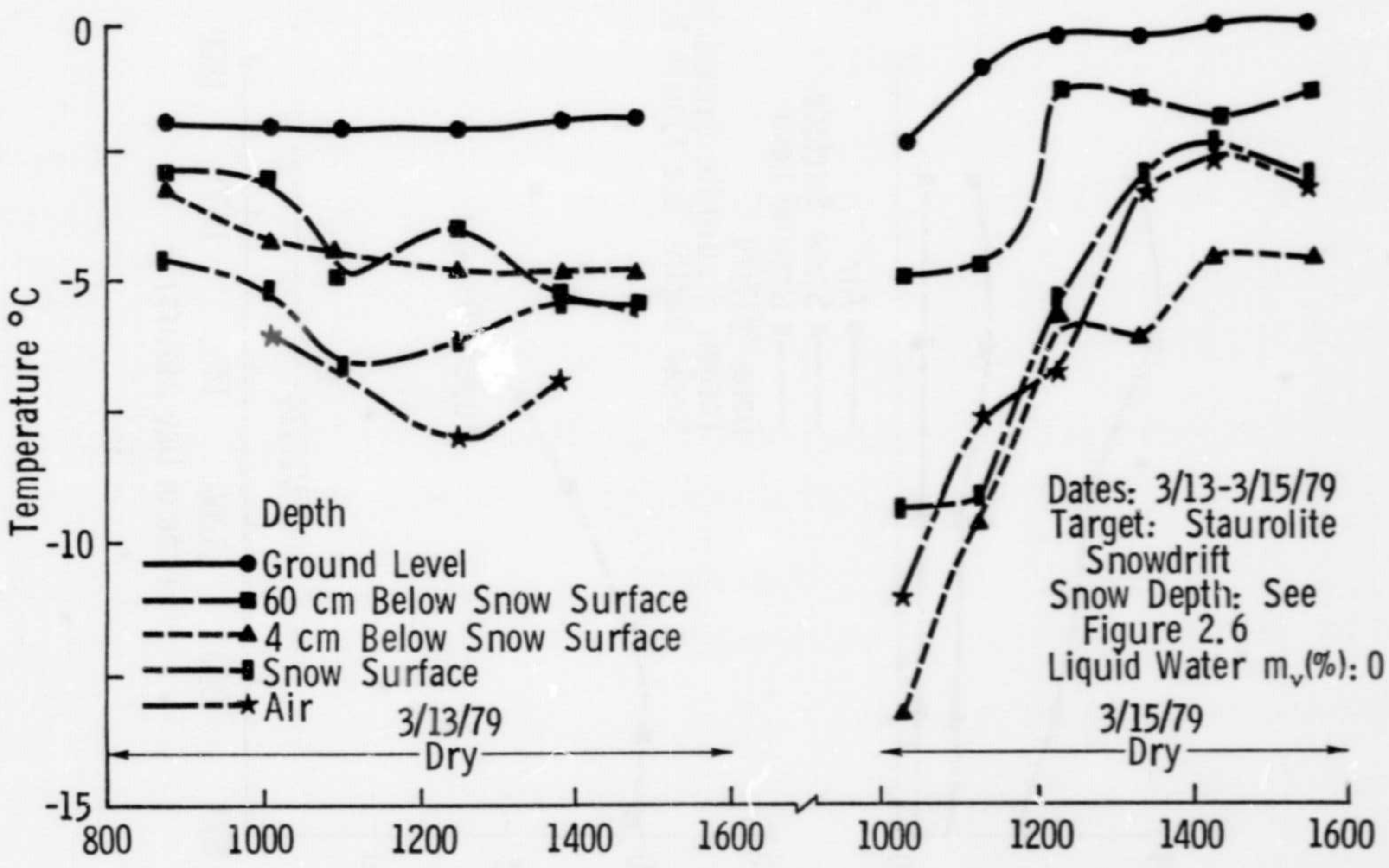
Figure 3.7. Angular response of σ^o to averaged wet and dry snow conditions at (a) 8.6 GHz, (b) 13.0 GHz, (c) 17.0 GHz, and (d) 35.6 GHz.


Liquid Water m_v (%): 0
Date: 3/14/79
Liquid Water m_v (%): 10
Date: 3/16/79
Frequency (GHz): 17.0
Scattering Coefficient σ^o (dB)
Angle of Incidence (Degrees)
15
10
5
0
-5
-10
-15
-20
-25
-30
0 10 20 30 40 50 60 70 80

(c)

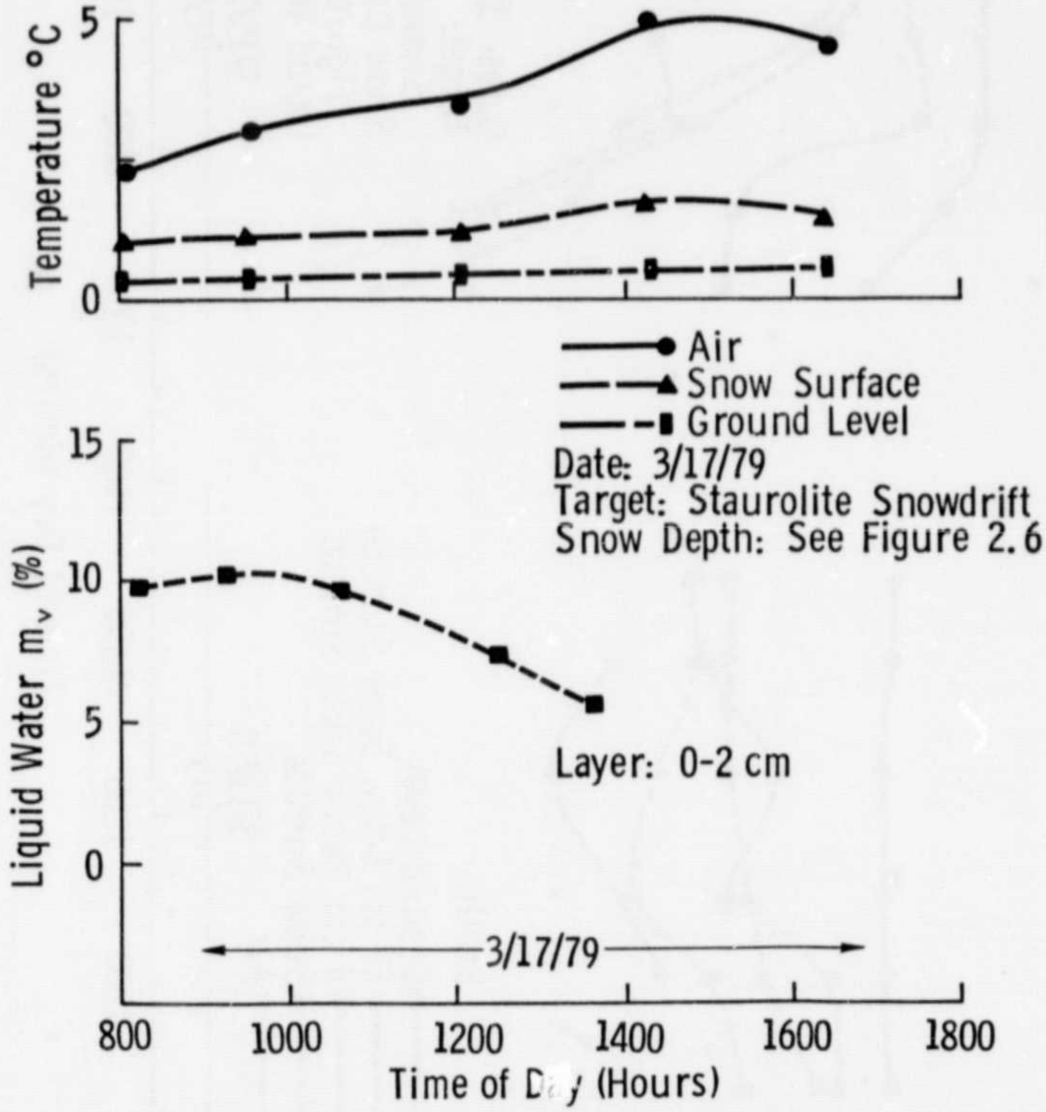

Liquid Water m_v (%): 0
Date: 3/14/79
Liquid Water m_v (%): 10
Date: 3/16/79
Frequency (GHz): 35.6
Scattering Coefficient σ^o (dB)
Angle of Incidence (Degrees)
15
10
5
0
-5
-10
-15
-20
-25
-30
0 10 20 30 40 50 60 70 80

(d)



(a)

Figure 3.8. Temperature variation over three days at the Staurolite snowdrift: (a) 3/13 - 3/15/79 and (b) 3/17/79 with m_v.


Temperature °C
5
0
Air
Snow Surface
Ground Level
Date: 3/17/79
Target: Staurolite Snowdrift
Snow Depth: See Figure 2.6
Liquid Water m_v (%)
15
10
5
0
Layer: 0-2 cm
3/17/79
800
1000
1200
1400
1600
1800
Time of Day (Hours)

(b)

TABLE 3.2

COMBINED MAS SYSTEM AND SNOW VARIATION UNDER "CONSTANT" CONDITIONS ON 3/13/79

(Liquid Water Content m_v = 0%)

Mean σ^o (dB)					
Angle of Incidence (degrees)	Polarization	Frequency (GHz)			
		8.6	13.0	17.0	35.6
40°	HH	-10.43	-10.04	- 9.18	- 7.97
	HV	-14.01	-14.58	-13.53	-11.45
50°	HH	-11.26	-11.01	- 9.62	- 7.26
	HV	-15.65	-16.83	-15.17	-11.67
75°	HH	-19.42	-19.34	-15.23	-13.23
	HV	-26.19	-24.87	-21.47	-17.65

Standard Deviations of σ^o (dB)					
Angle of Incidence (degrees	Polarization	Frequency (GHz)			
		8.6	13.0	17.0	35.6
40°	HH	1.32	1.12	1.4	2.58
	HV	0.8	0.5	0.89	2.49
50°	HH	0.8	1.2	1.27	1.01
	HV	0.87	0.84	0.64	1.15
75°	HH	1.15	0.99	0.96	0.71
	HV	0.77	1.0	0.73	0.97

the mean and standard deviations of the backscattered power. It can be seen that the variation is again less than 1.4 dB for all frequencies except 35.6 GHz. These figures are consistent with the stability measurement of March 14, 1979. The second visit to the same site was on the 15th of March, 1979. The weather was again sunny, clear and cold. Air temperature peaked at -2.7° in the afternoon. Snow liquid water was again zero, but the soil had now thawed. The backscatter data is given in Appendix B.

The last diurnal set from this field was obtained on March 17, 1979. A warm-weather trend had continued since the 16th of March and air temperatures went up to 5° C. The weather was generally cloudy, with a light mist and a steady 10-mph wind. The soil was thawed and peak snow liquid water content of more than 10% by volume was measured.

These conditions provided an opportunity to evaluate the σ^o response to "saturated" snow. For the period from 0800 to 1300, the 0-2 cm snow layer had liquid water contents above 6%. The subsurface layers were also wet; m_v of the 2-5 cm layer was 10.8% at noon. As will be illustrated in Section 3.4, the response to m_v tends to saturate for values of m_v greater than 5%. If the standard deviation and mean value of σ^o are calculated for this day (Table 3.3) it is observed that the mean values behave as expected (lower than the dry snow σ^o mean values) and the standard deviation values are on the same order ($\approx$ 1 dB) as for dry snow conditions.

The results of the above variation analyses indicate that under weather conditions that ensure either dry or wet snow conditions, "constant" values of σ^o can be expected. During the "in between" weather conditions, the σ^o response may be quite variable due to differing rates

TABLE 3.3

COMBINED MAS SYSTEM AND SNOW VARIATION UNDER "CONSTANT" WET SNOW CONDITIONS ON 3/17/79

(Liquid Water Content m_v = 6 to 10%)

Mean σ^o (dB)					
Angle of Incidence (degrees)	Polarization	Frequency (GHz)			
		8.6	13.0	17.0	35.6
40°	HH	-15.64	-19.46	-18.48	-16.60
	HV	-23.08	-23.08	-24.71	-27.39
50°	HH	-18.38	-22.15	-21.09	-18.35
	HV	-24.88	-26.42	-26.51	-28.2

Standard Deviations of σ^o (dB)					
Angle of Incidence (degrees)	Polarization	Frequency (GHz)			
		8.6	13.0	17.0	35.6
40°	HH	0.91	0.90	0.97	0.8
	HV	0.77	0.76	0.91	1.22
50°	HH	0.87	0.86	0.76	0.94
	HV	0.88	0.79	0.56	0.77

of melting of the snowpack. Section 3.4 covers analyses of the differing melt conditions.

3.2 Roughness Response

The effects of surface roughness on the microwave backscatter and emission from snow were examined in a previous report (Stiles and Ulaby, 1980b). It was observed that surface roughness exercises a minor effect on σ^{o} for dry snow (Figure 3.9), but when the snow surface layer is wet, the effects of surface roughness become significant. A description of the surface geometry is given in Section 3.2.2. In this section, a theoretical model for the backscatter from snow is applied to the 1977 data acquired in the 8-18 GHz region to evaluate the effects of surface roughness on σ^{o}. Following this evaluation, the experimental data measured in 1979 for the artifically-roughed snow surfaces are presented.

3.2.1 Backscatter Model

In the following approach, the snow is modeled by spherical scatterers and radiative transfer methods are applied (England, 1975; Leader, 1975; Tsang and Kong, 1978). The air-snow boundary is assumed to be a Gaussian random surface which satisfies physical optics and is describable by Kirchhoff surface scatter theory (Fung and Eom, 1980).

For the microwave bands up to Ku-band and for reasonably sized snow crystals, the snow layer can be formulated as an inhomogeneous layer with Rayleigh scatterers, an irregular air-snow interface and a smooth snow-ground interface. Snow-ground roughness effects may be added; however, these effects are believed to be secondary to the ones which were included. The geometry is shown in Figure 3.10. Within the inhomogeneous layer the upward and downward intensity matrix, I^{+} and I^{-}, are assumed to satisfy the radiative transfer equation,

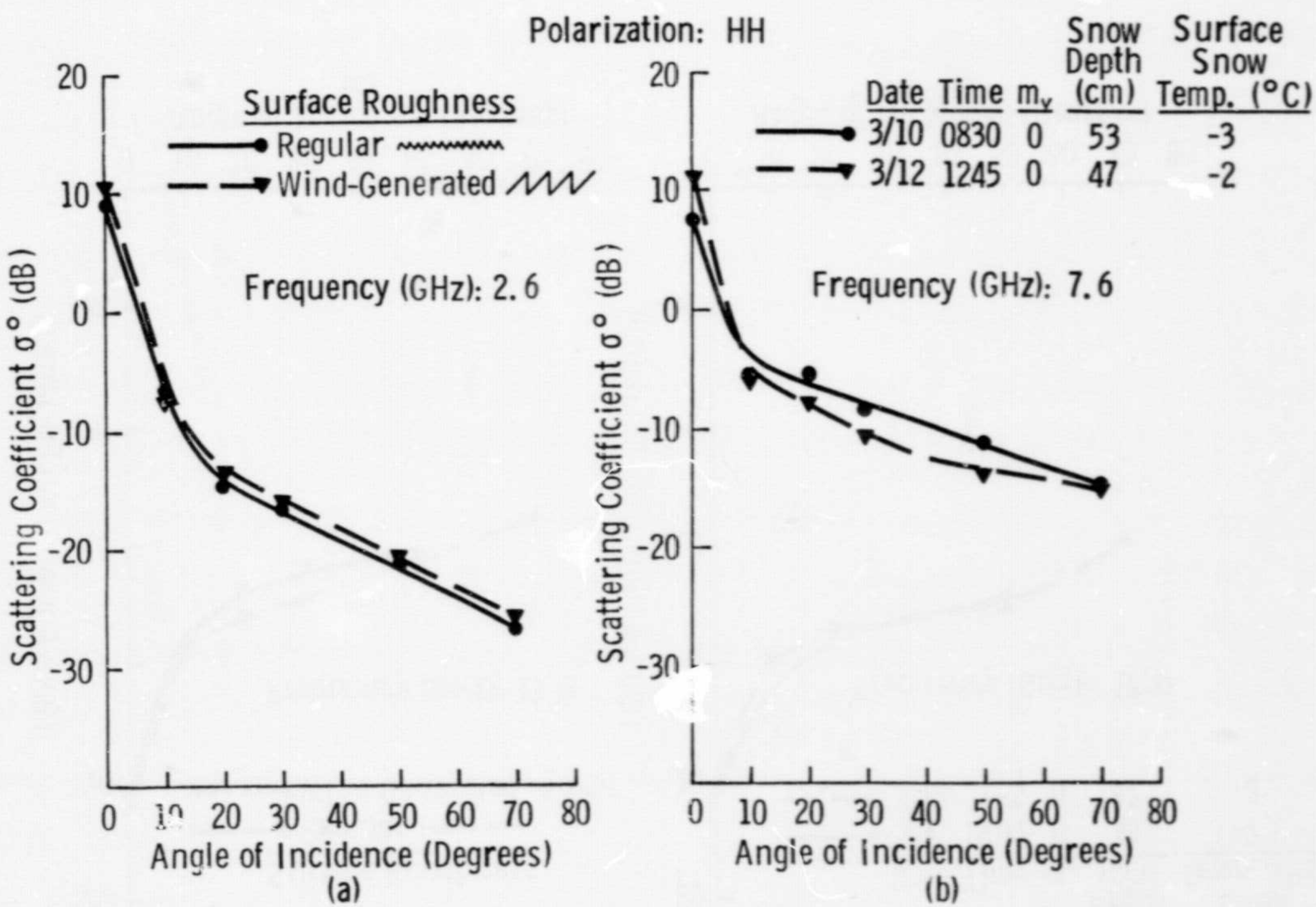
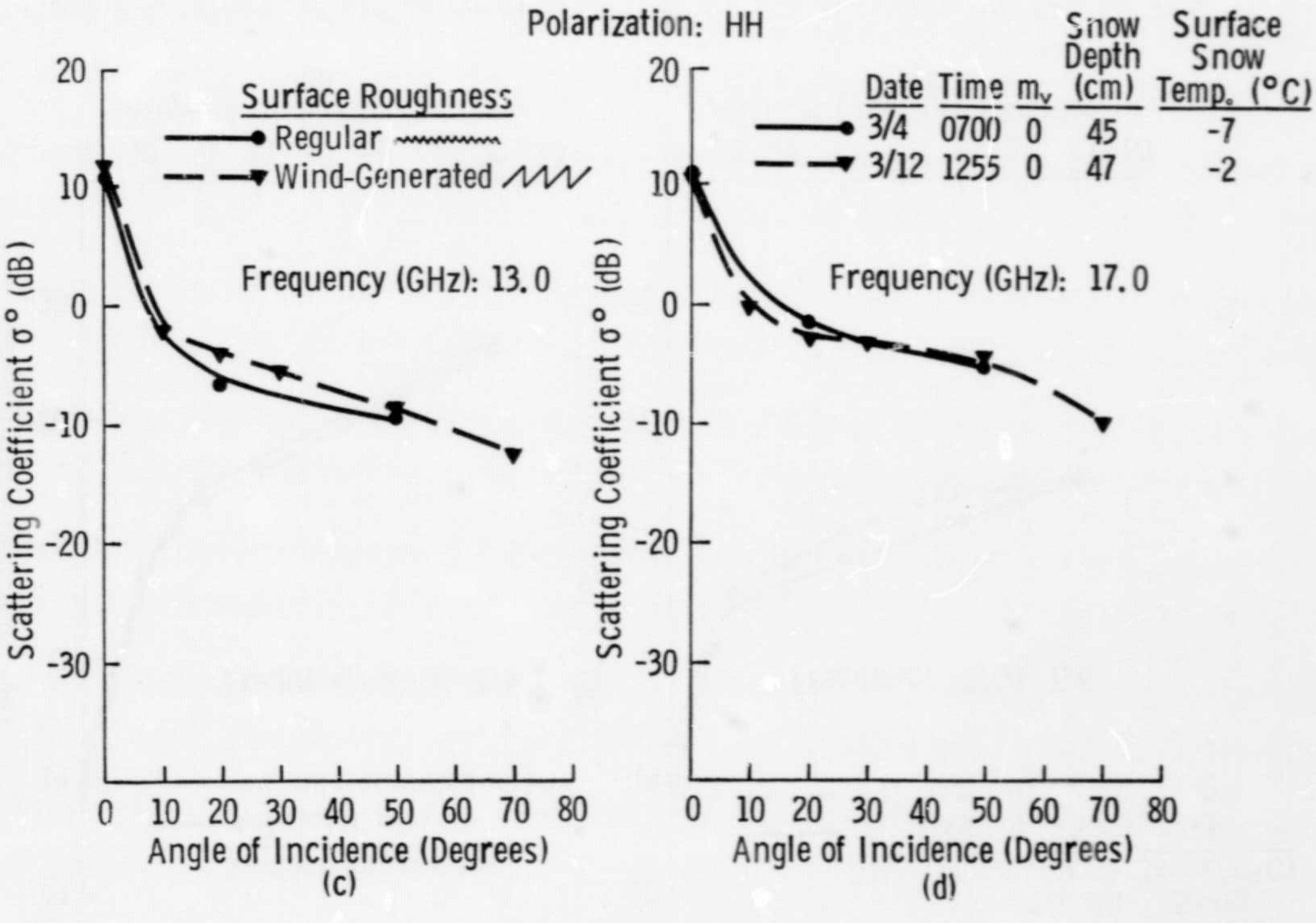
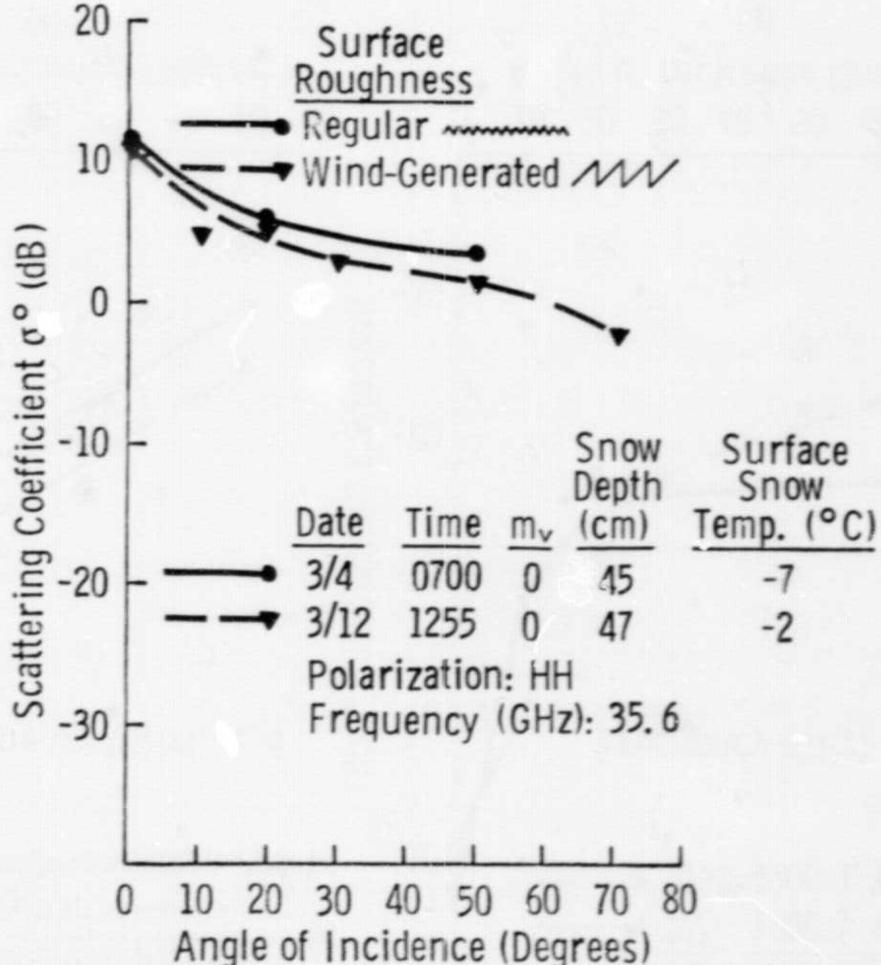
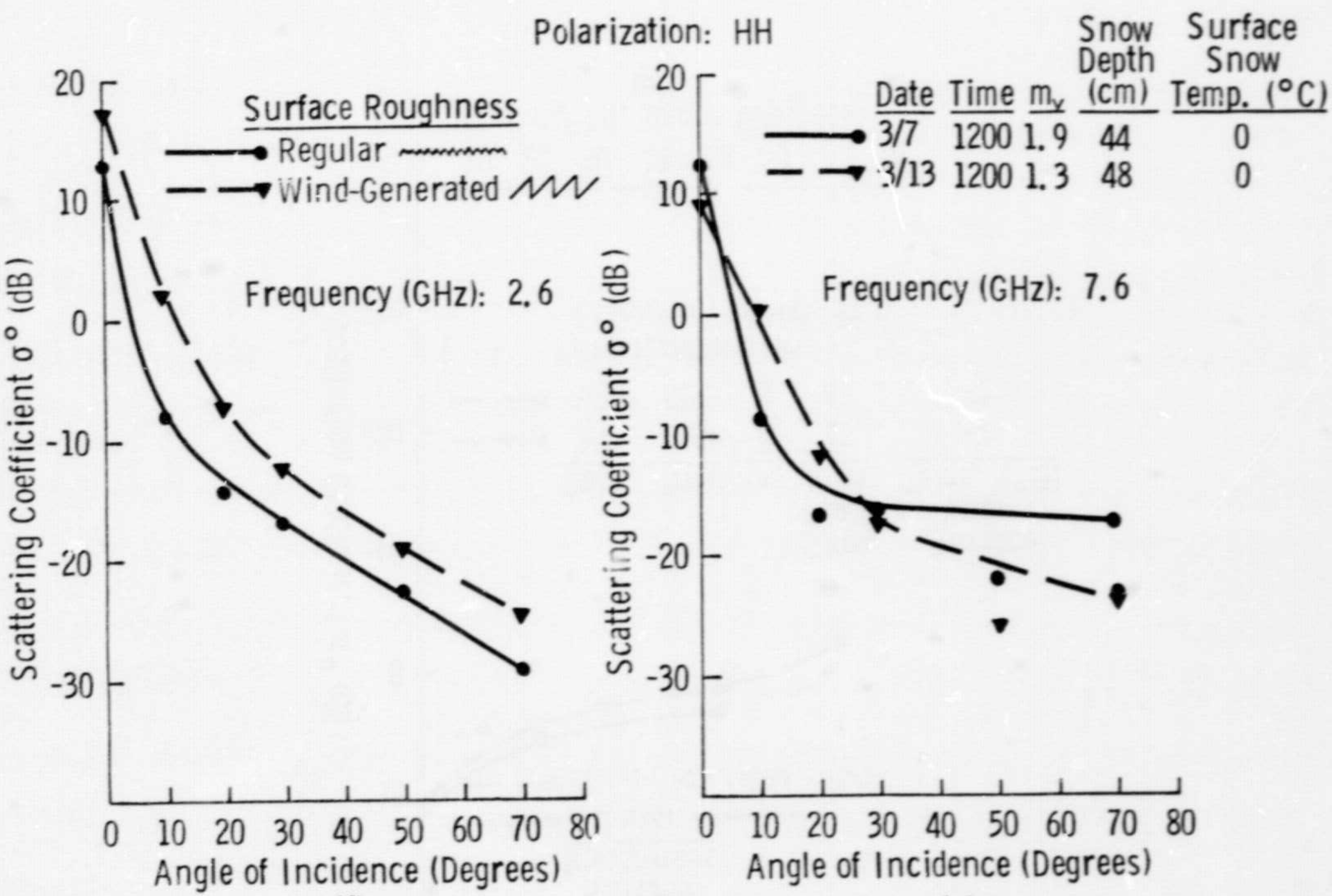


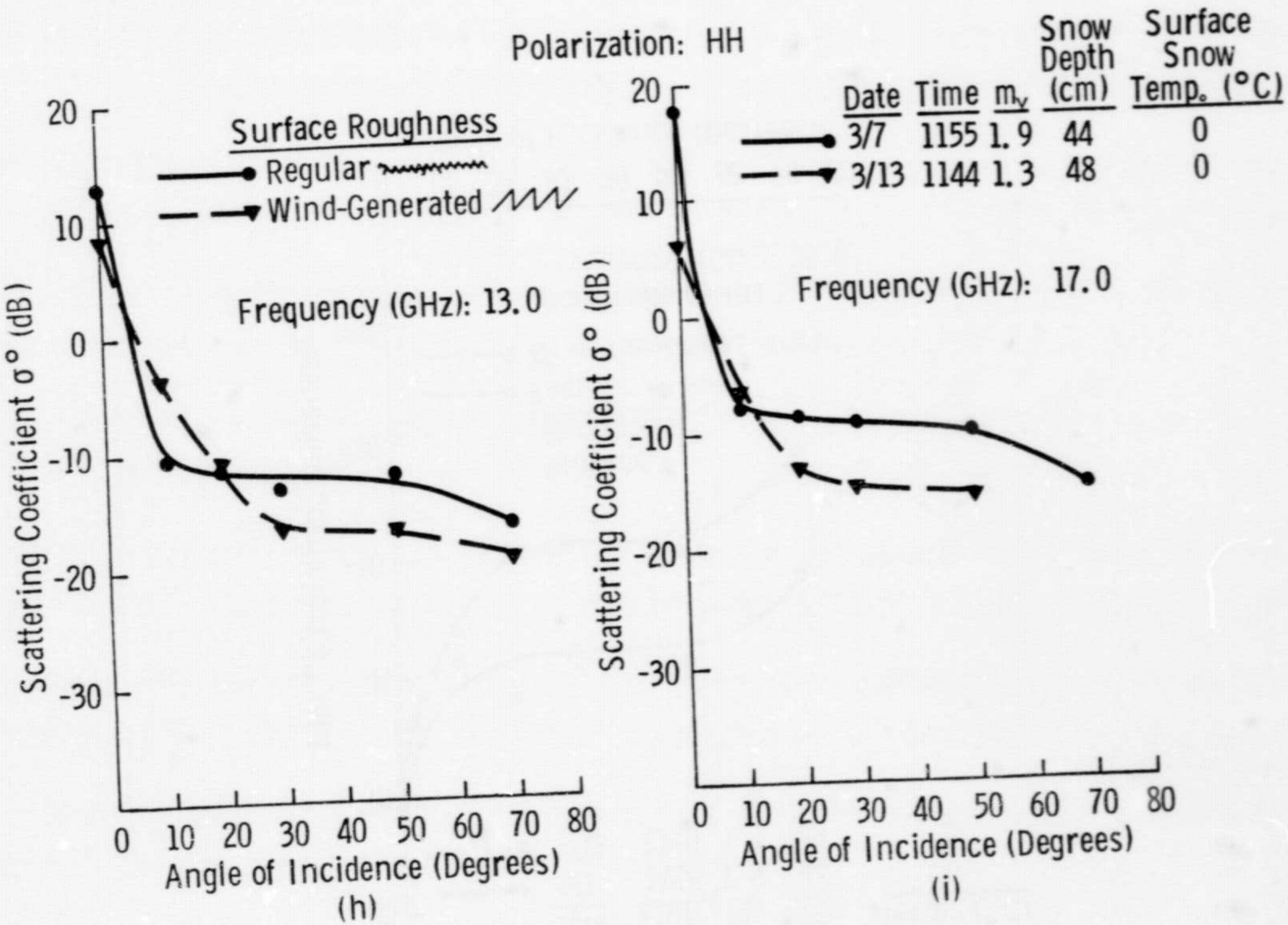
Figure 3.9. Effects of surface roughness on σ^o of dry snow at (a) 2.6, (b) 7.6, (c) 13.0, (d) 17.0, and (e) 35.6 GHz and wet snow at (f) 2.6, (g) 7.6, (h) 13.0, (i) 17.0, and (j) 35.6 GHz.

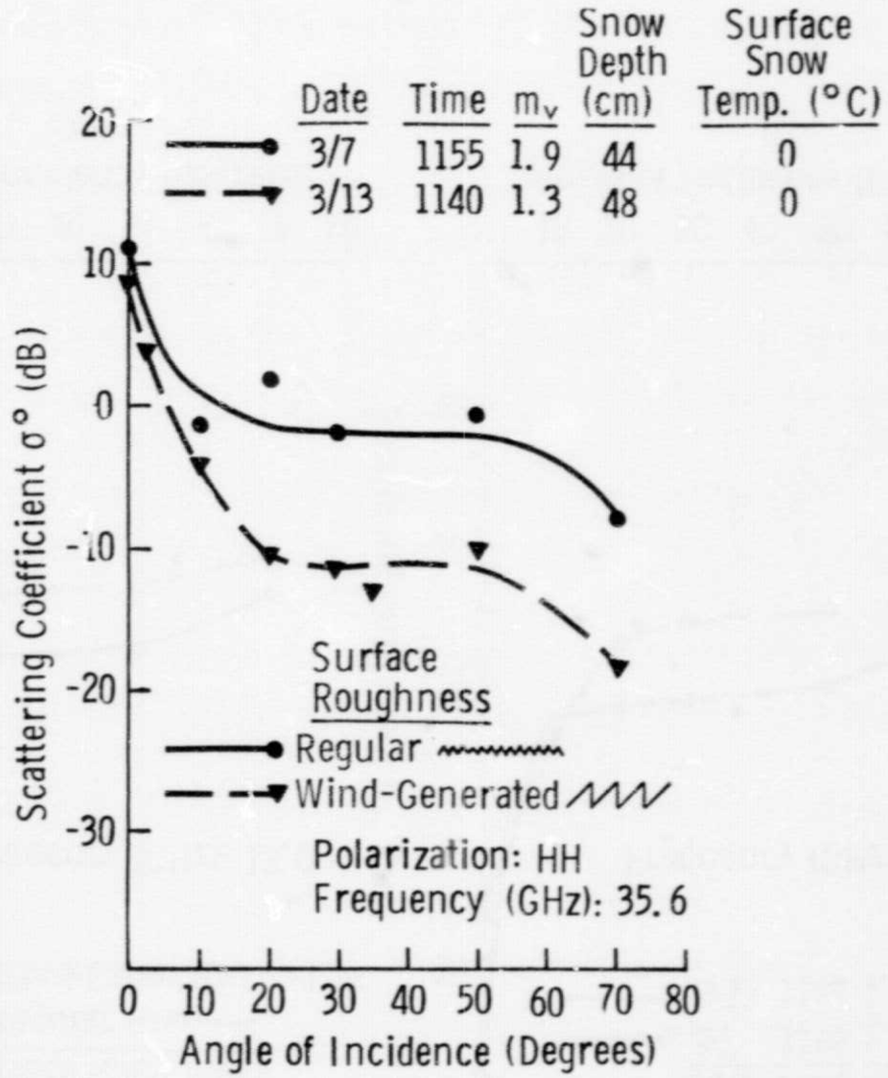

Polarization: HH
Surface Roughness
Regular
Wind-Generated
Frequency (GHz): 13.0
Scattering Coefficient σ° (dB)
20
10
0
-10
-20
-30
0 10 20 30 40 50 60 70 80
Angle of Incidence (Degrees)
(c)
Date Time m_v Snow Depth (cm) Surface Snow Temp. (°C)
3/4 0700 0 45 -7
3/12 1255 0 47 -2
Frequency (GHz): 17.0
Scattering Coefficient σ° (dB)
Angle of Incidence (Degrees)
(d)


Surface Roughness
Regular
Wind-Generated
Scattering Coefficient σ° (dB)
20
10
0
-10
-20
-30
Date
Time
m_v
Snow Depth (cm)
Surface Snow Temp. (°C)
3/4
0700
0
45
-7
3/12
1255
0
47
-2
Polarization: HH
Frequency (GHz): 35.6
0
10
20
30
40
50
60
70
80
Angle of Incidence (Degrees)
(e)


Polarization: HH
Surface Roughness
Regular
Wind-Generated
Frequency (GHz): 2.6
Scattering Coefficient σ° (dB)
Angle of Incidence (Degrees)
Date Time m_v Snow Depth (cm) Surface Snow Temp. (°C)
3/7 1200 1.9 44 0
3/13 1200 1.3 48 0
Frequency (GHz): 7.6
Scattering Coefficient σ° (dB)
Angle of Incidence (Degrees)

(f) (g)


Polarization: HH
Surface Roughness
Regular
Wind-Generated
Frequency (GHz): 13.0
Scattering Coefficient σ° (dB)
20
10
0
-10
-20
-30
0 10 20 30 40 50 60 70 80
Angle of Incidence (Degrees)
(h)
Date Time m_v Snow Depth (cm) Surface Snow Temp. (°C)
3/7 1155 1.9 44 0
3/13 1144 1.3 48 0
Frequency (GHz): 17.0
Scattering Coefficient σ° (dB)
Angle of Incidence (Degrees)
(i)


Date Time m_v Snow Depth (cm) Surface Snow Temp. (°C)
3/7 1155 1.9 44 0
3/13 1140 1.3 48 0
Scattering Coefficient σ° (dB)
20
10
0
-10
-20
-30
Surface Roughness
Regular
Wind-Generated
Polarization: HH
Frequency (GHz): 35.6
0 10 20 30 40 50 60 70 80
Angle of Incidence (Degrees)

(j)

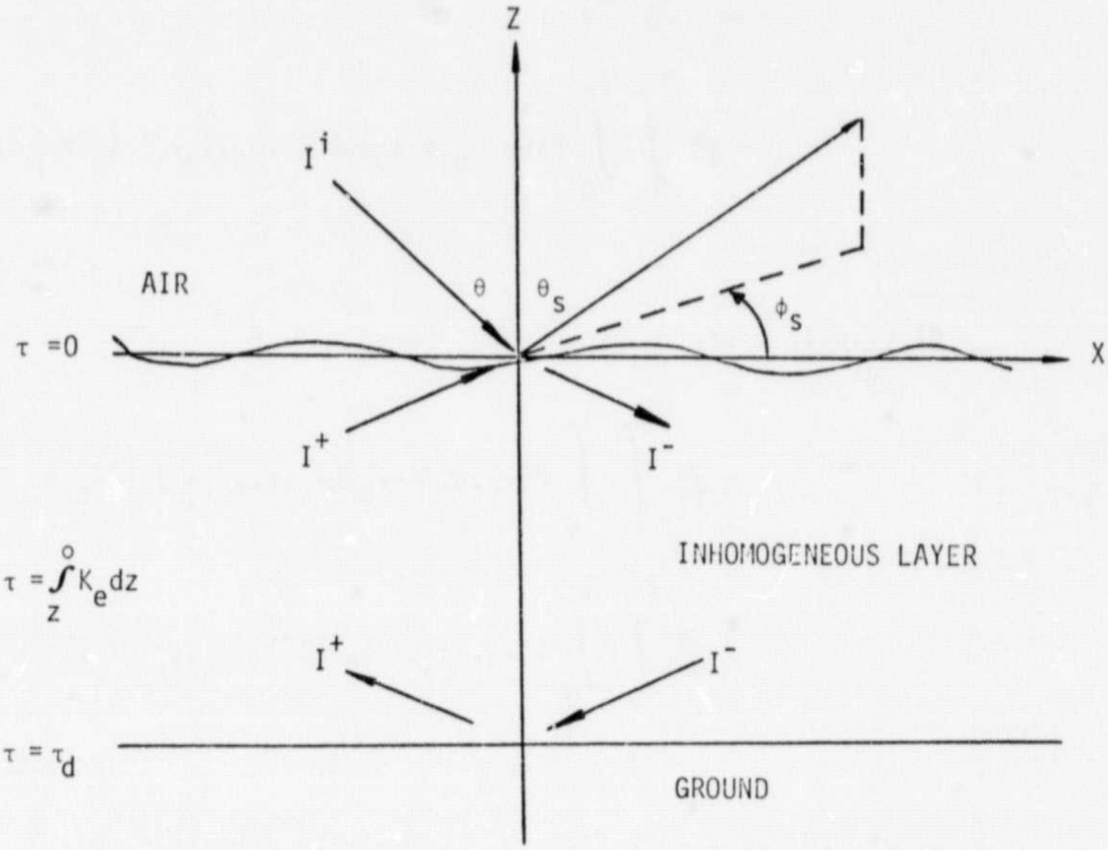


Figure 3.10 Geometry of the scatter problem.

$$\mu \frac{dI^{+}(\tau,\mu,\phi)}{d\tau} = I^{+}(\tau,\mu,\phi)$$

$$- \frac{\omega}{4\pi} \int_0^{2\pi} \int_0^1 P(\mu,\mu_o,\phi-\phi_o)[I^{+}(\tau,\mu_o,\phi_o) + I_s^{+}]d\mu_o d\phi_o$$

$$- \frac{\omega}{4\pi} \int_0^{2\pi} \int_0^1 P(\mu,-\mu_o,\phi-\phi_o)[I^{-}(\tau,\mu_o,\phi_o) + I_s^{-}]d\mu_o d\phi_o$$

(3.1)

$$-\mu \frac{dI^{-}(\tau,\mu,\phi)}{d\tau} = I^{-}(\tau,\mu,\phi)$$

$$- \frac{\omega}{4\pi} \int_0^{2\pi} \int_0^1 P(-\mu,\mu_o,\phi-\phi_o)[I^{+}(\tau,\mu_o,\phi_o) + I_s^{+}]d\mu_o d\phi_o$$

$$- \frac{\omega}{4\pi} \int_0^{2\pi} \int_0^1 P(-\mu,-\mu_o,\phi-\phi_o)[I^{-}(\tau,\mu_o,\phi_o) + I_s^{-}]d\mu_o d\phi_o$$

(3.2)

where $\mu = \cos\theta$; I^{+}, I^{-} are column matrices containing the first three Stokes parameters; I_s^{+}, I_s^{-} are the direct intensities; $P(\mu,\mu_o,\phi-\phi_o)$ is the Rayleigh phase matrix; ω is the albedo of the scattering layer and τ is the optical depth.

The upward intensity due to an incident intensity, I^{i}, which appears in the direct intensity expression, is found by solving (3.1) and (3.2) subject to the following boundary conditions. At $\tau = \tau_d$ the condition is

$$I^{+} = R_g I^{-}$$

where R_g is the ground reflectivity matrix. At the top boundary $\tau = 0$, the condition is

$$I^-(\mu,\phi) = \frac{1}{4\pi}\int_0^{2\pi}\int_0^1 S_R(\mu,\mu_o,\phi-\phi_o)I^+(\mu_o,\phi_o)d\mu_o d\phi_o \tag{3.3}$$

where the surface scatter function is the same as for an emission case. Once $I^+(0,\mu,\phi)$ is found inside the layer, the upward intensity transmitted from the layer into air can be found from the relation,

$$I^+(\mu,\phi) = \frac{1}{4\pi}\int_0^{2\pi}\int_0^1 S_T(\mu,\mu_o,\phi-\phi_o)I^+(0,\mu_o,\phi_o)d\mu_o d\phi_o \tag{3.4}$$

where S_T is the transmitted bistatic scattering coefficient as for an emission case.

The forward and backward intensities are functions of the azimuth angle. In addition, some correlation between spatially orthogonal field components exists which requires the inclusion of the third Stokes parameter. Thus, the approach selected to solve (3.1) and (3.2) is to expand both the components of the intensity matrices and the components of the volume and surface scatter matrices in Fourier series with respect to the azimuth angle. Each Fourier component is then treated independently. Since the assumed Rayleigh phase matrix consists of only three Fourier components, there is no need to consider more components in any of the intensity matrices or surface scattering matrices.

Theoretical results showing the dependence on the snow parameters are given in Figures 3.11 to 3.13. Variation of the surface height

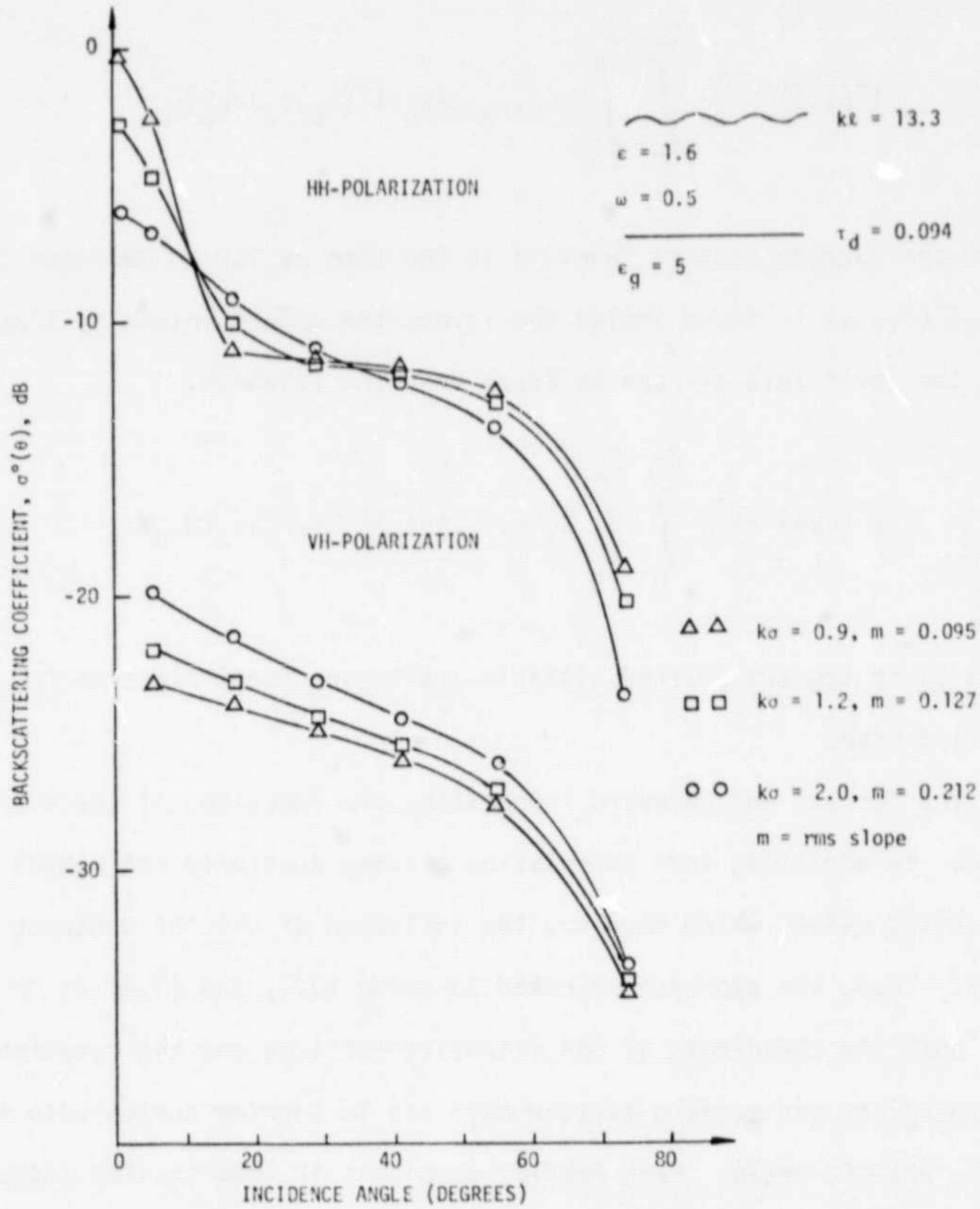


Figure 3.11 Effects of change in surface standard deviation.

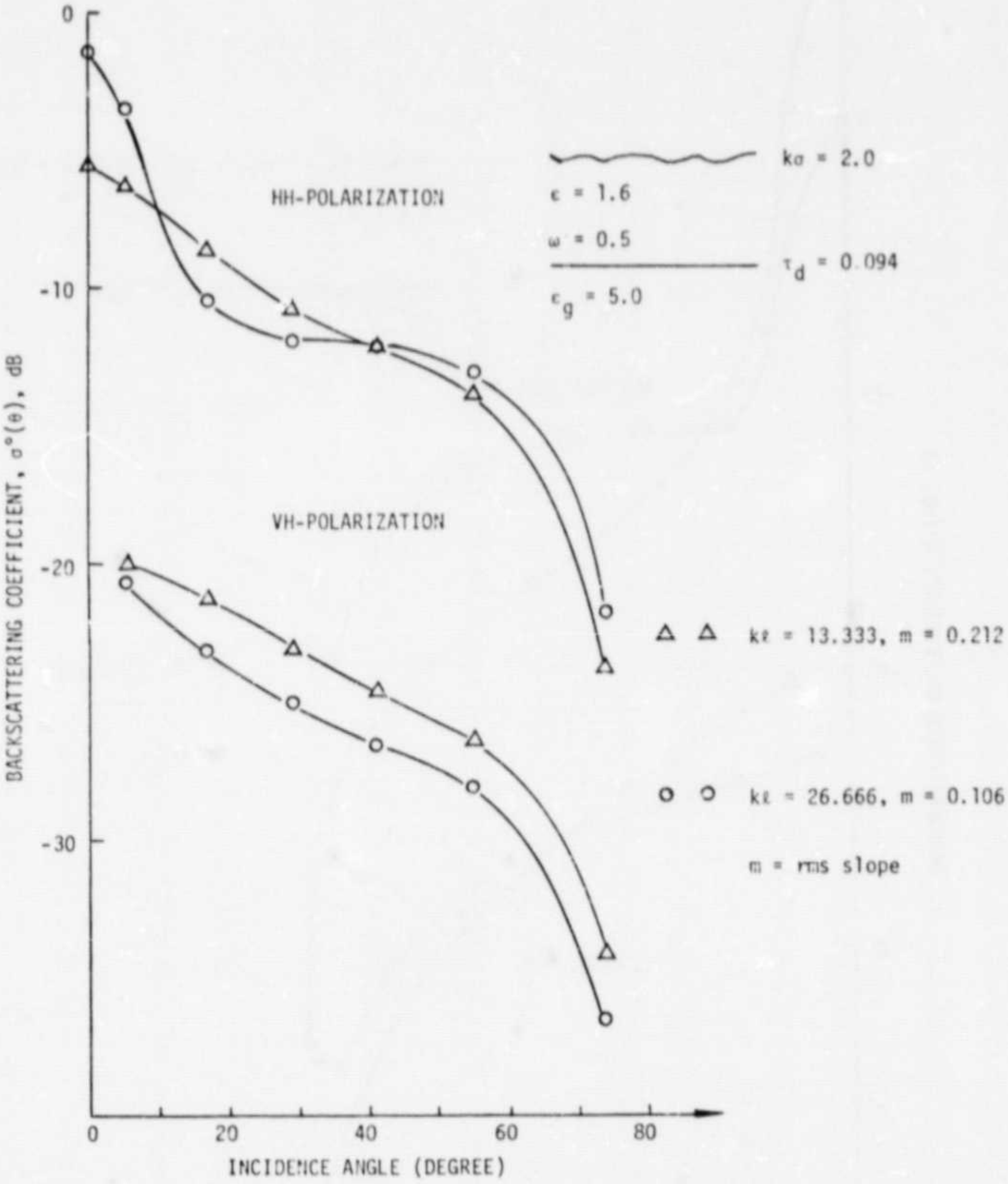


Figure 3.12 Effects of change in surface correlation.

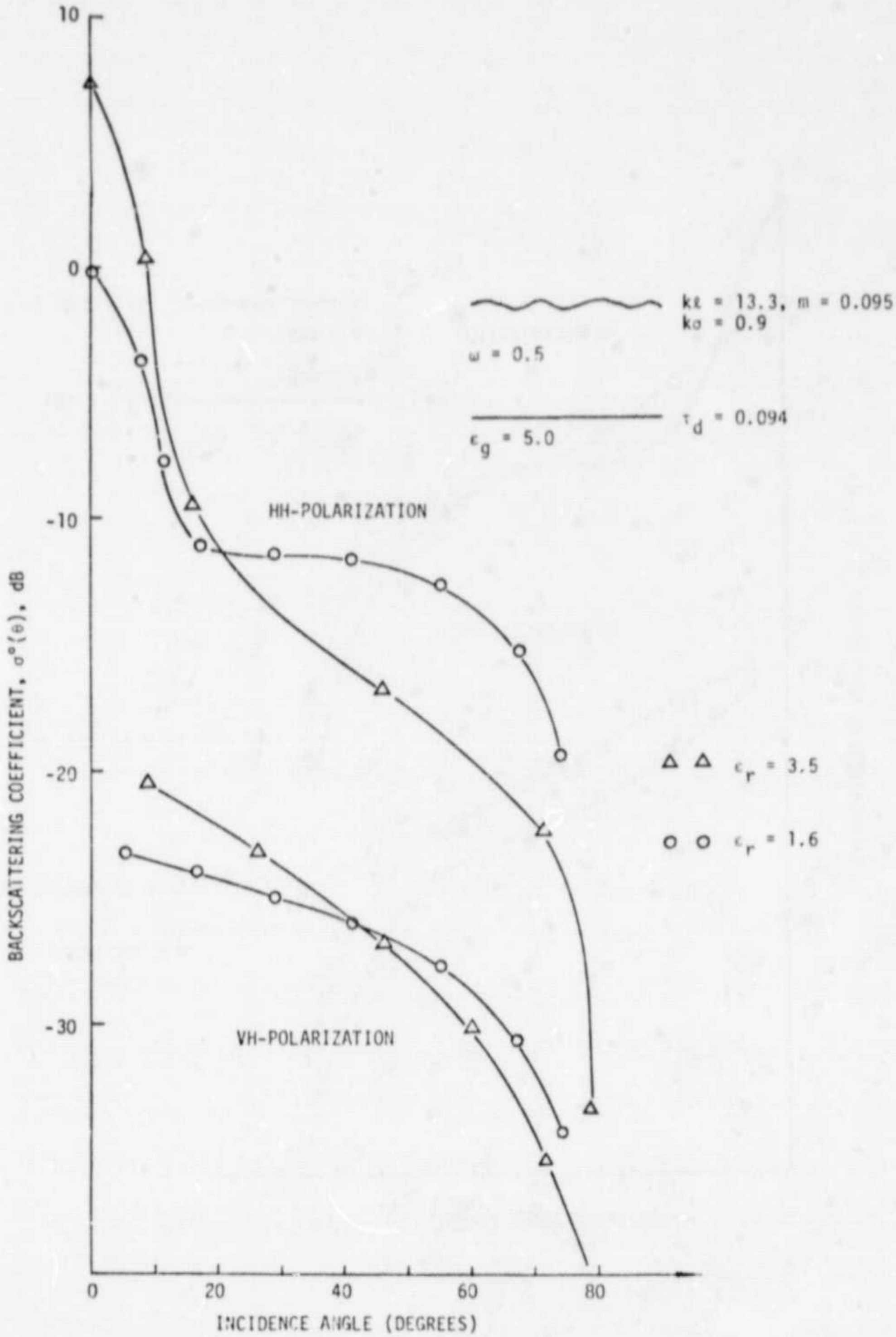


Figure 3.13 Effects of change in layer permittivity.

standard deviation for dry snow (Figure 3.11) has a large effect near nadir but causes only a slight decrease in the volume scatter effect at the large incidence angles. The cross polarized behavior is also dependent on the surface. Surface correlation length effects are illustrated in Figure 3.12. As the length decreases, the surface appears rougher but again in the 30° to 60° angle of incidence range, the sensitivity is minor.

The effect of a change in the average permittivity of the Rayleigh layer corresponding to an increase in liquid water is shown in Figure 3.13. As a result of the larger disparity in dielectric constant (ε_r = 3.5 for the wet snow case) at the air-snow boundary, now the surface contribution is much larger in relation to the volume scatter contribution. The steeper angular roll-off indicative of surface scatter is apparent from the curves.

3.2.2 Comparison with Measurements

The microwave measurements for comparison with the model were obtained in 1977 (Figure 3.9). Similar system descriptions and experimental procedures as described in Section 2.0 apply to the 1977 σ^0 data. A change in surface geometry was caused by strong southerly winds on 3/11/77 allowing investigation of surface effects on similar snowpack characteristics. Prior to this date, the surface was characterized by high spatial frequency variations with small amplitudes (about 1/4 cm) and no preferred orientation, while the "wind-generated" surface is characterized by large, smooth facets connected by ridges. A surface profile is approximately a saw-tooth pattern with a spatial frequency of 30 cm and an

amplitude of 2 cm. The microwave observations were made with the sensor "looking" in the direction of downwind.

Figures 3.14 to 3.19 present the results of the model as applied to the wet and dry snow conditions for the two surface geometry cases. The small amplitude roughness is termed the "regular" case in the figures, while the other roughness is the "wind-generated." The selection of surface parameters follows approximately the physical dimensions of the roughness scale. Thus, the standard deviation of the regular surface is taken to be around 0.2 cm while that of the wind-generated around 0.8 cm. The estimate of the dry snow permittivity follows the measurement of Cummings (1952). For all the cases shown, general agreement in level and trend is observed. The disagreement in the case of dry snow at normal incidence is probably due to rough ground contribution which is yet to be included in modeling. The surface parameters chosen at different frequencies to realize a good fit are self-consistent; however, it was found that different values were needed for describing a consistent fit for passive data (Fung, et al., 1980). It is therefore concluded that both active and passive measurements are needed to resolve this discrepancy in the effects of surface roughness.

3.2.3 Brookings Roughness Experiment

An experiment to measure the σ^{o} response to extreme levels of snow surface roughness was conducted on March 19, 1979. The snow on this day was very wet due to rainfall during the previous night. The snow depth varied between 70 cm and 100 cm, the soil was thawed and saturated, and the air temperature was about 2° C. Following observations of the undisturbed

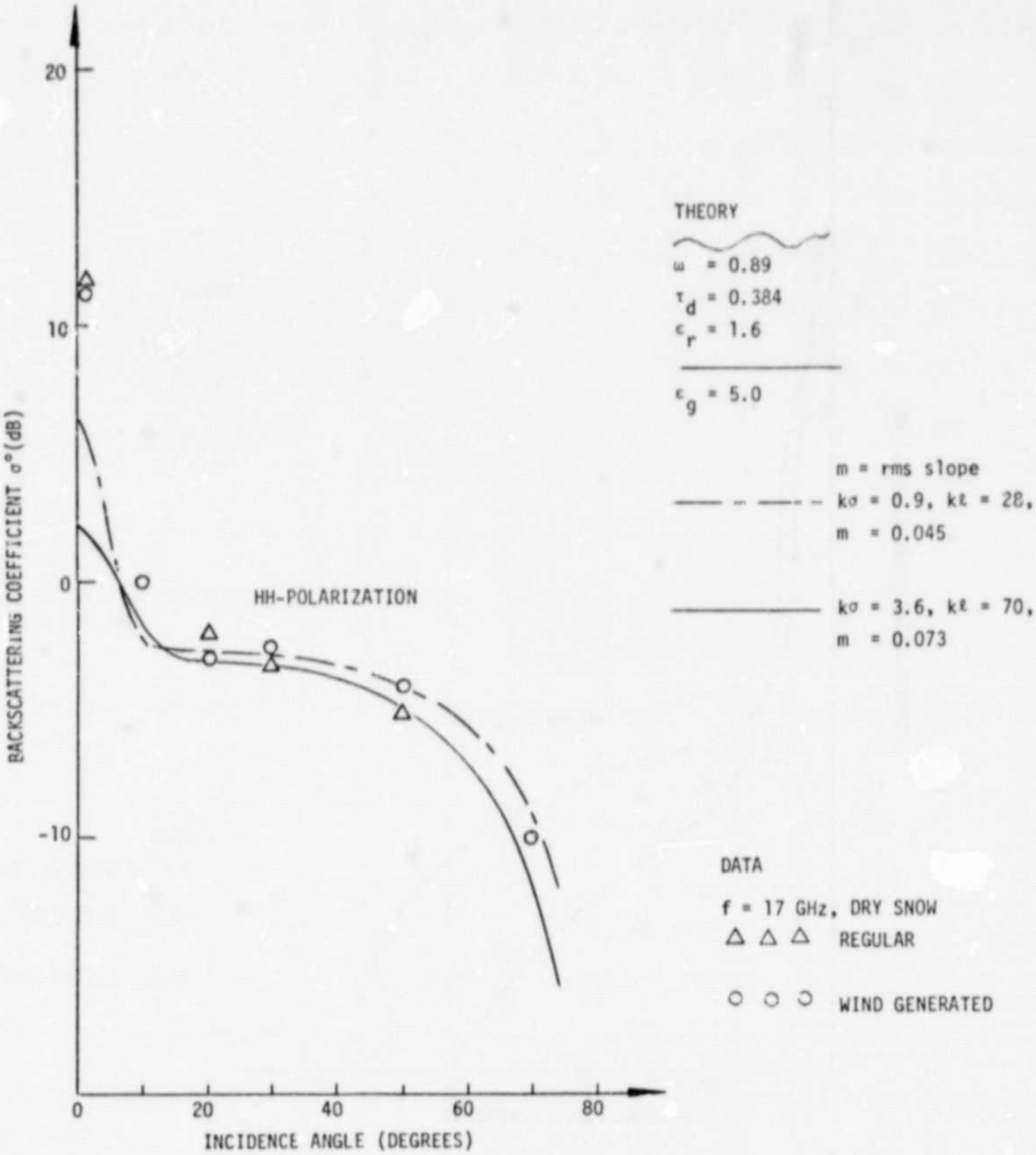


Figure 3.14 Comparison between theory and measurements at 17 GHz for dry snow.

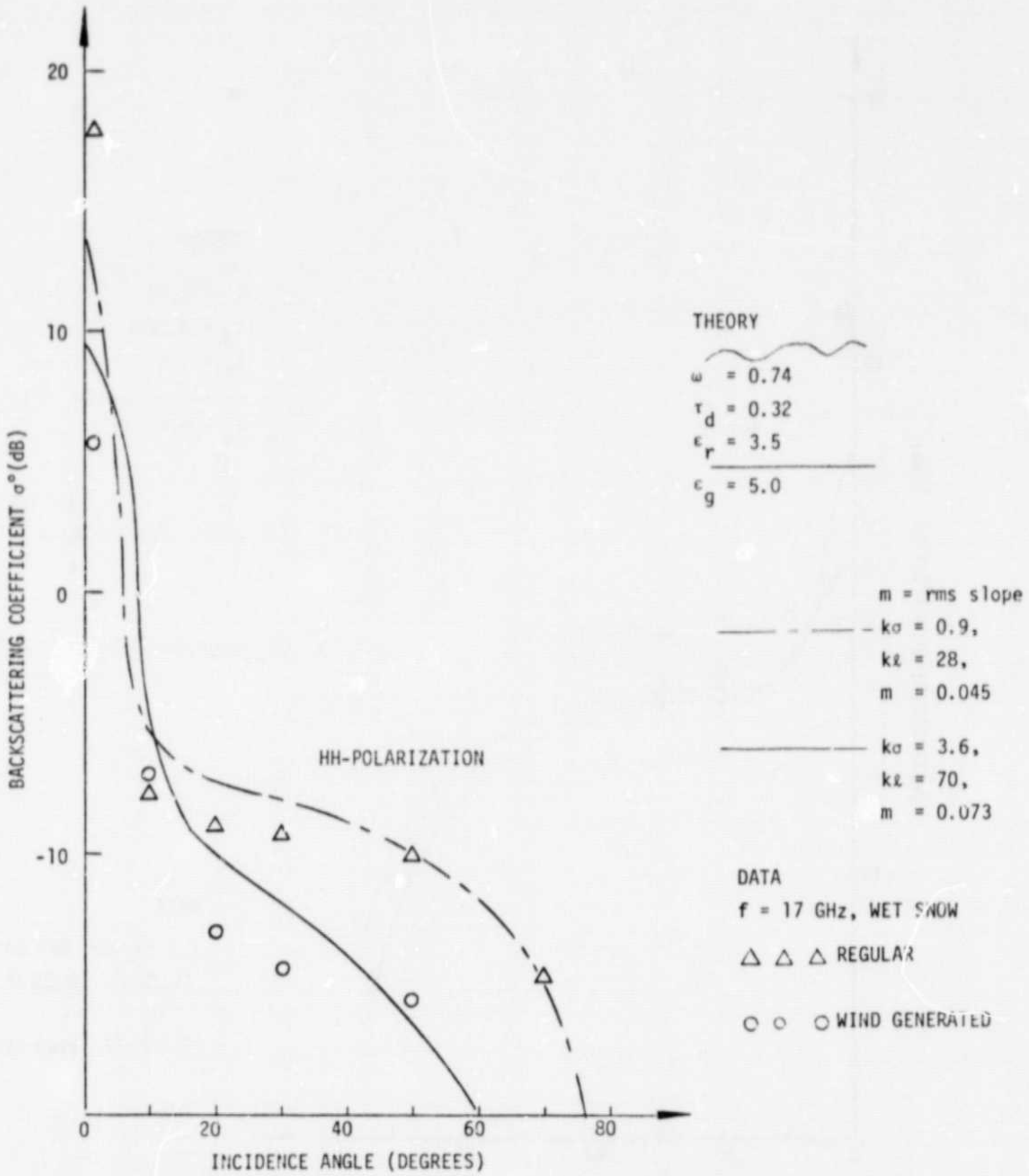


Figure 3.15 Comparison between theory and measurements at 17 GHz for wet snow.

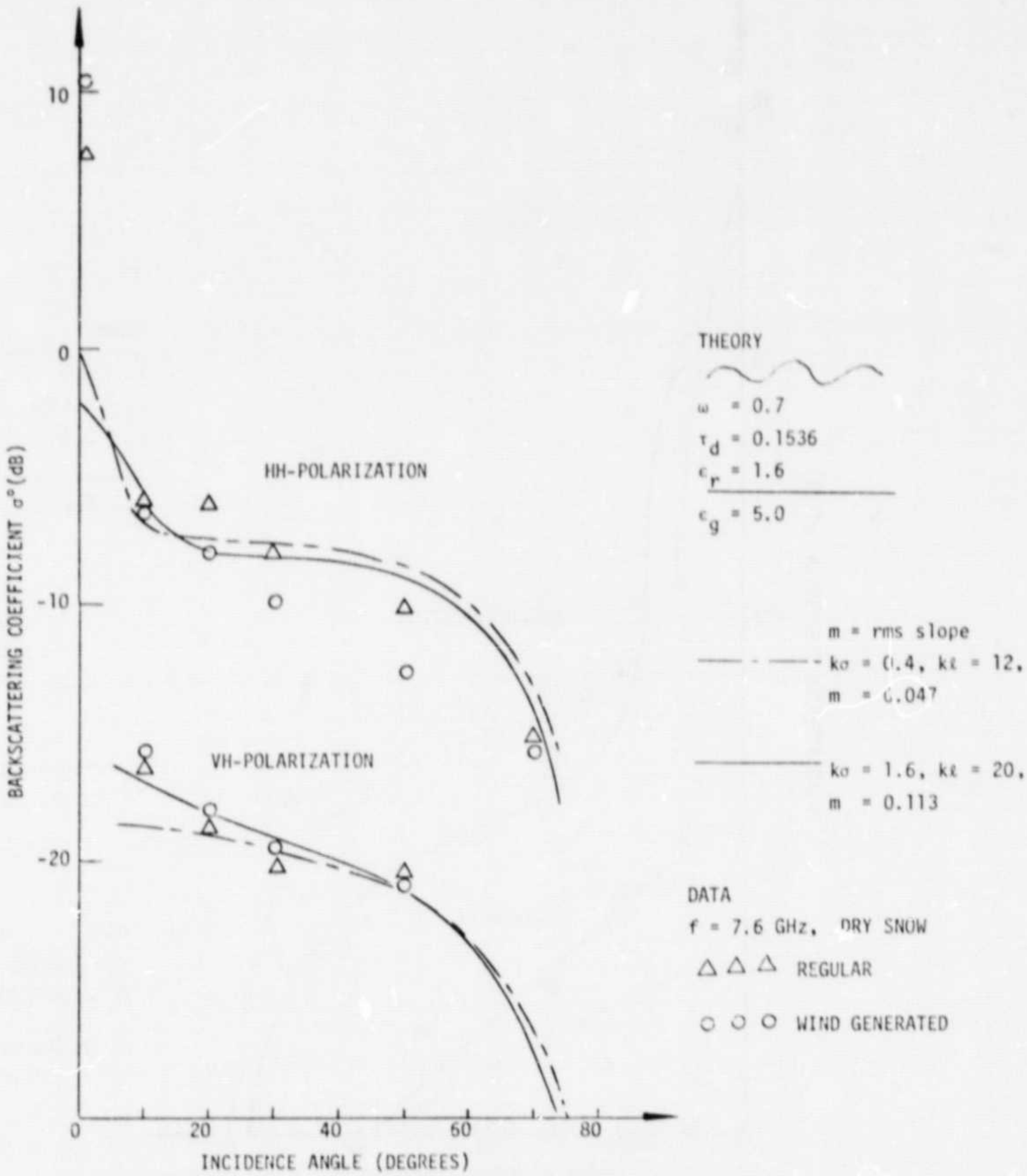


Figure 3.16 Comparison between theory and measurements at 7.6 GHz for dry snow.

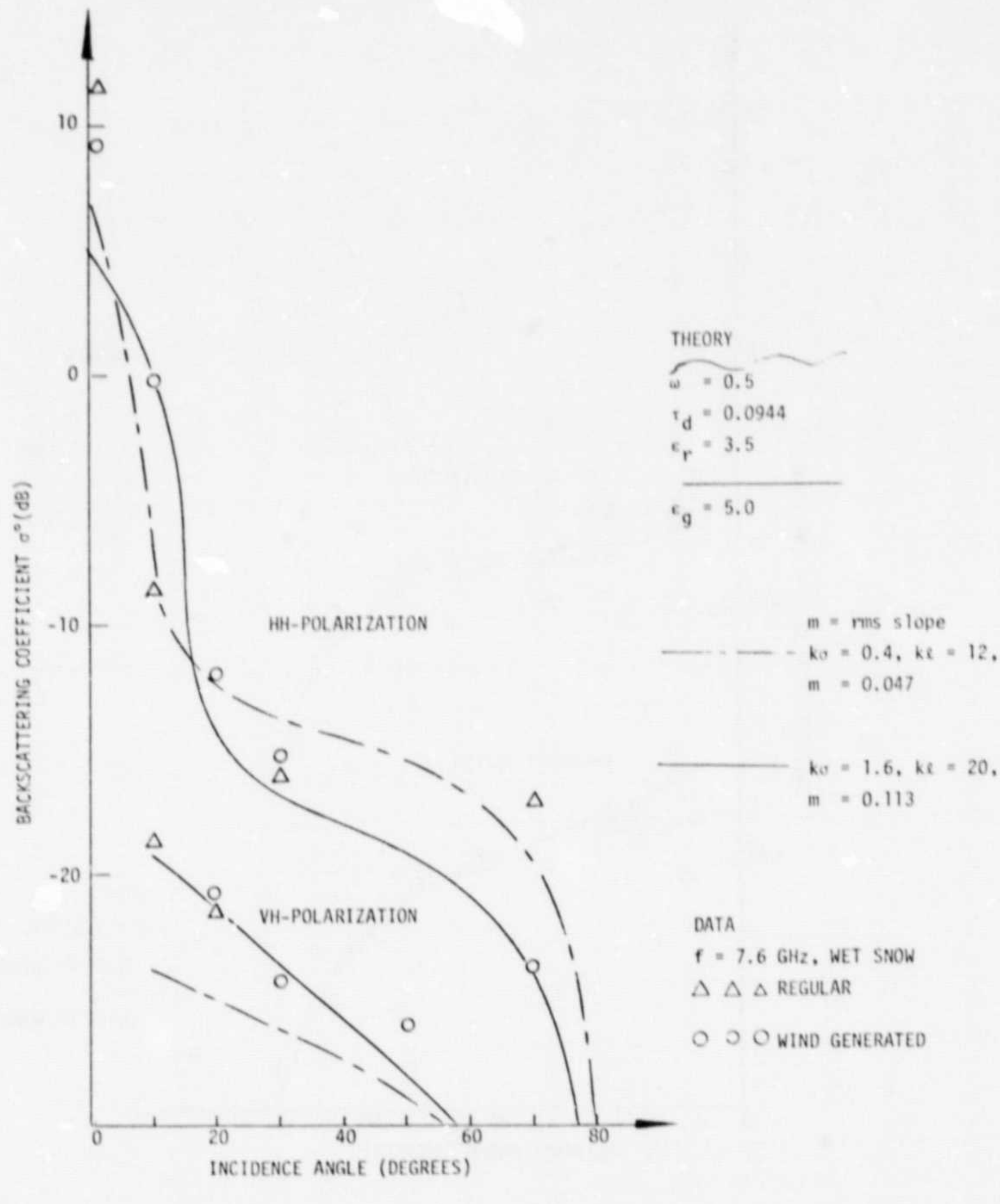


Figure 3.17 Comparison between theory and measurements at 7.6 GHz for wet snow.

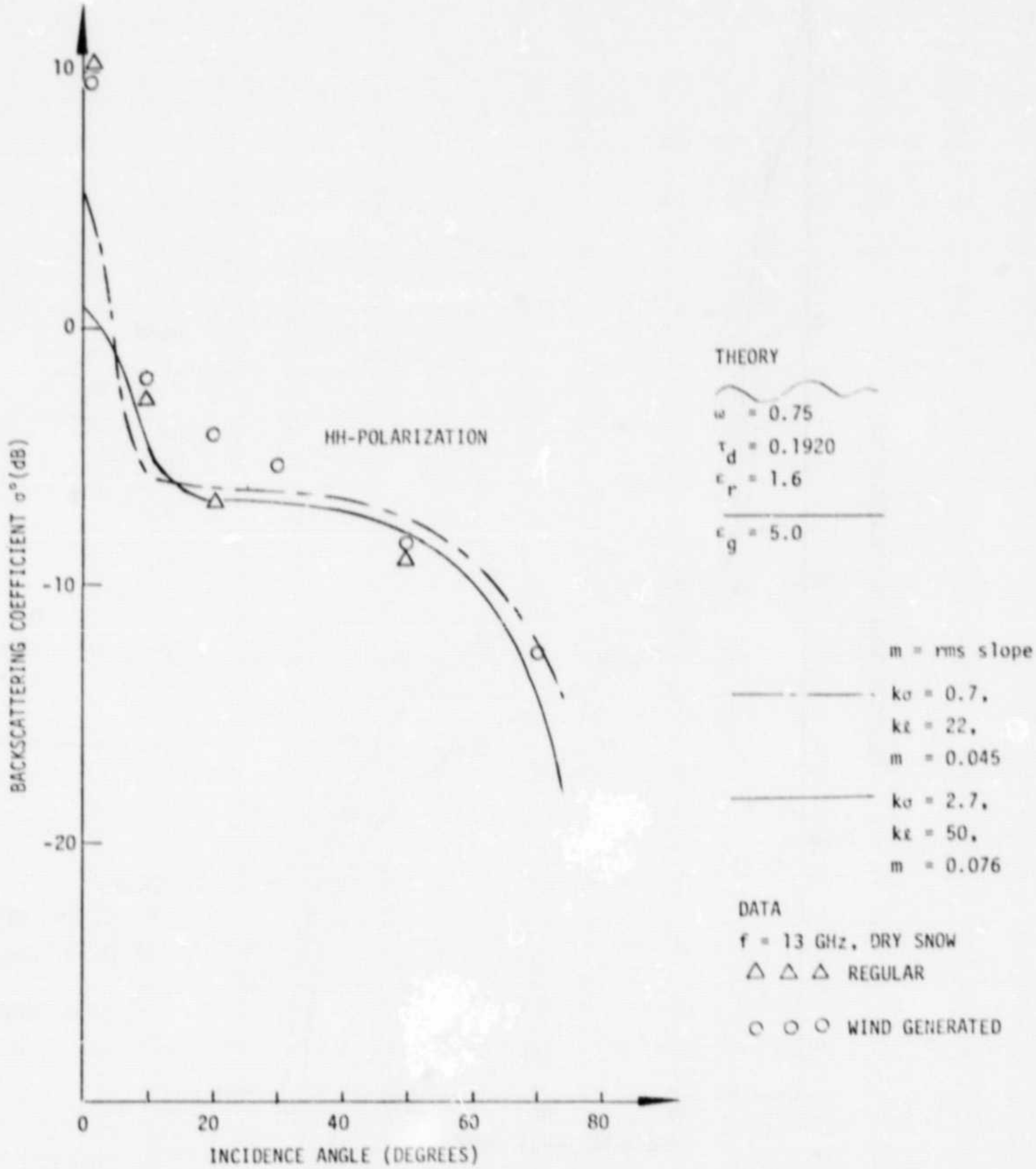


Figure 3.18 Comparison between theory and measurements at 13 GHz for dry snow.

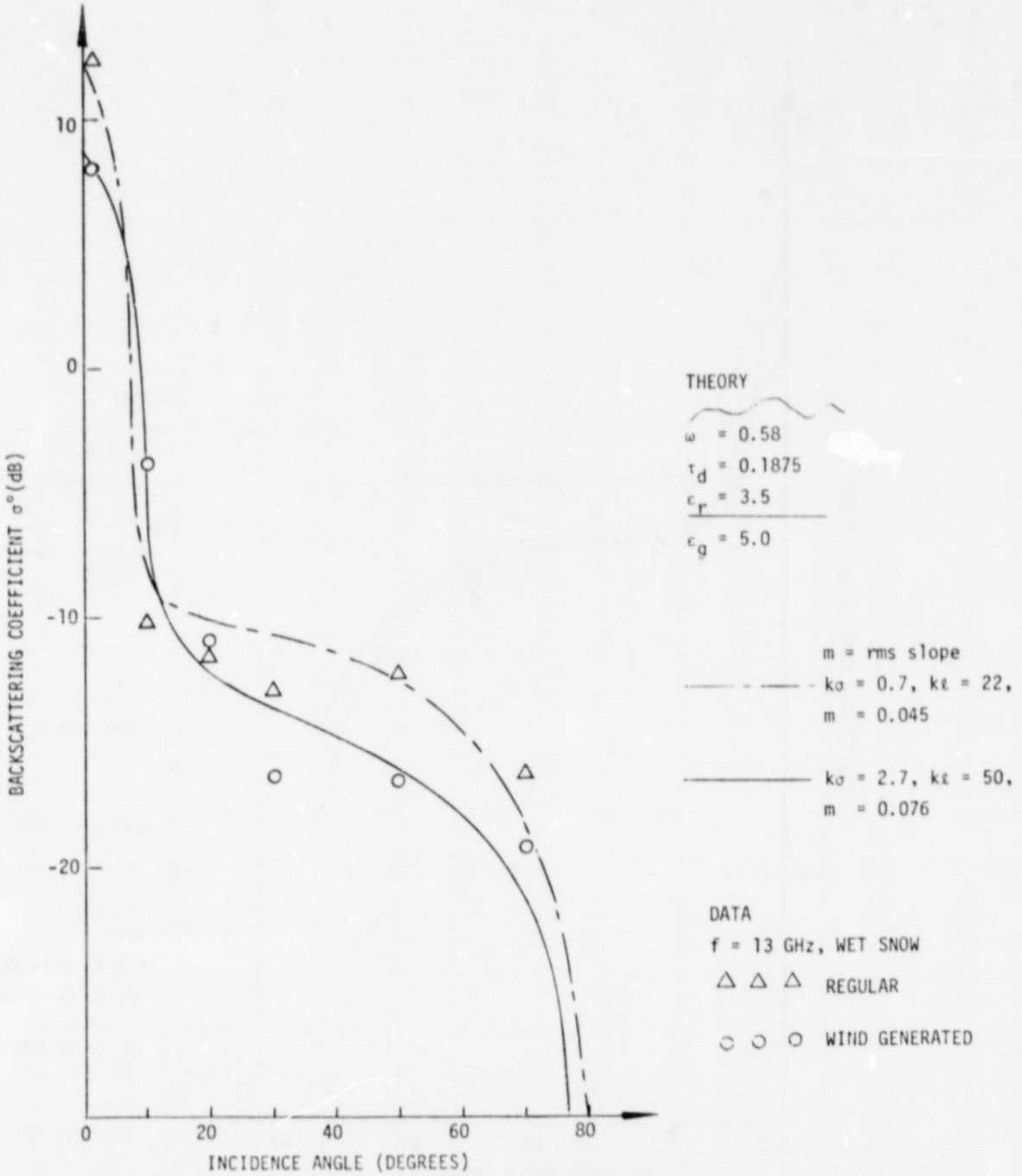


Figure 3.19 Comparison between theory and measurements at 13 GHz for wet snow.

smooth snow during the early part of the day, an additional data set was acquired for each of two artificially-generated surface roughness conditions. Photographs showing the snow surface against a metal plate are given in Figure 2.9.

Figure 3.20 shows the measured angular variation of σ^o for each of the three different surface roughness conditions. At all frequencies (Figures 3.20a - 3.20d), σ^o decreases rapidly with angle from nadir for the smooth (undisturbed) surface, particularly close to nadir. Considering that the snow was fairly wet throughout the snowpack, the backscatter at frequencies above 8 GHz is essentially dominated by surface scatter, with probably negligible contributions by the snow volume. As surface roughness is increased, σ^o assumes a weaker angular variation, as expected for surface scatter. For the smooth surface, the 0° to 50° dynamic range of σ^o decreased from 30 dB at 8.6 GHz to 22 dB at 35 GHz. In contrast, σ^o of the "very rough" surface, when extrapolated to 50°, had a dynamic range of 6 dB at 8.6 GHz decreasing to 2 dB at 35 GHz. Therefore for wet snow, the surface roughness plays a dominant role in the backscatter from the snowpack and its effects are similar to those for wet soils (Ulaby, et al., 1978b).

In addition to the experimental curves, a theoretical model fit using the two-scale surface model of Fung and Eom (1981) was applied to the smooth surface data and provides a good fit. This model could not be applied to the rougher surfaces because the rms height conditions violate the model assumptions; in addition, the model was not applied to the 35 GHz data for the same reason. The small-scale correlation length was assumed to vary directly with wavelength, while the large-scale correlation length was selected for the best fit. The quantity $k_{\rho E}$, the equivalent correlation length for the surface, is based on the combined two-scale correlation lengths.

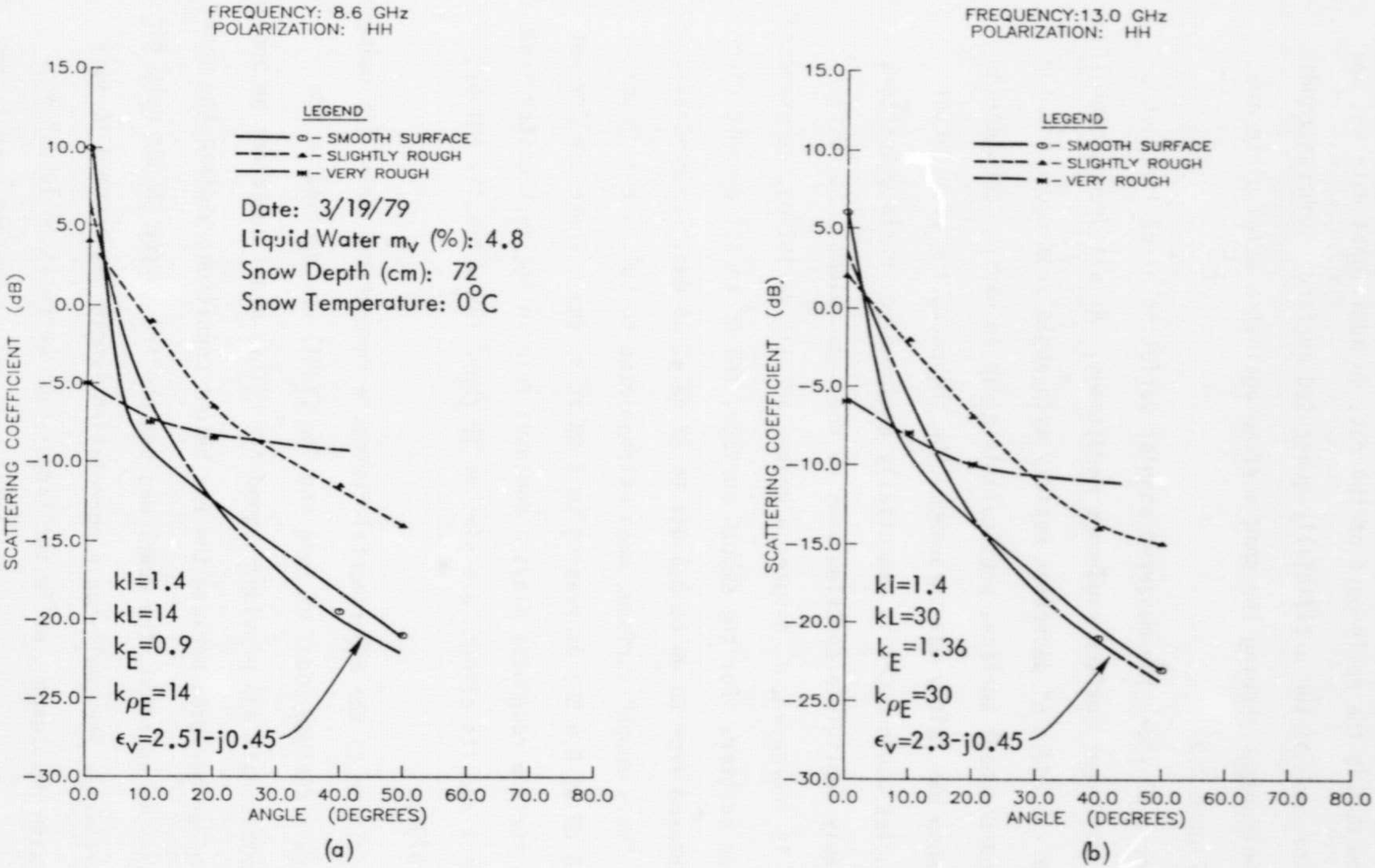
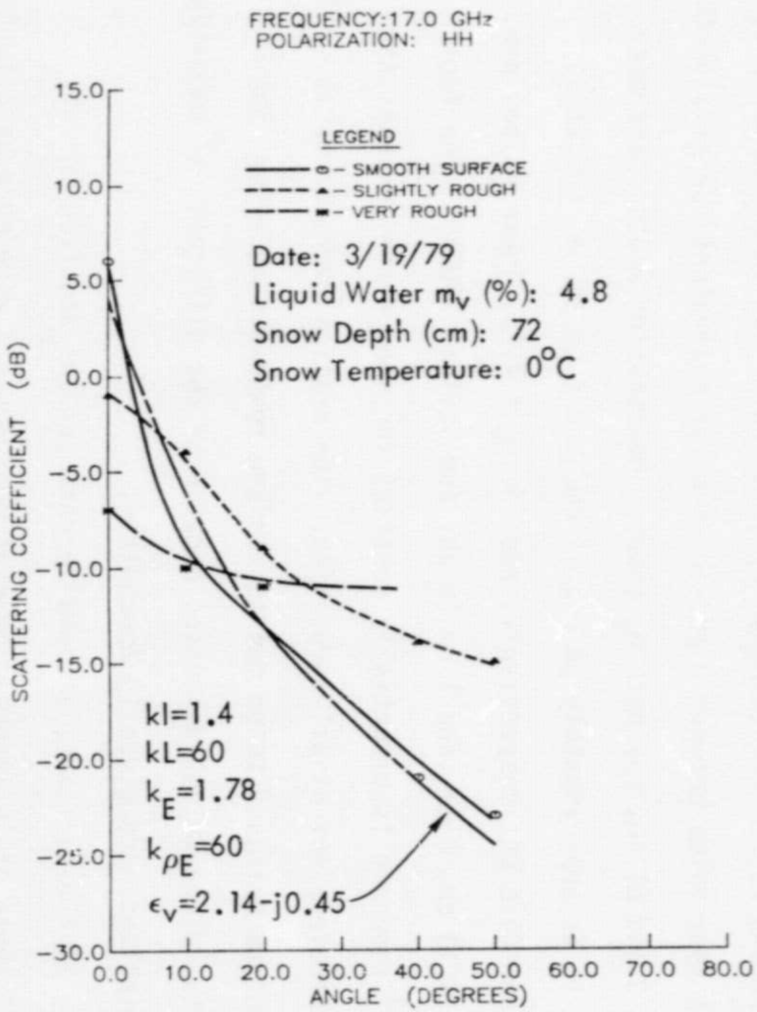
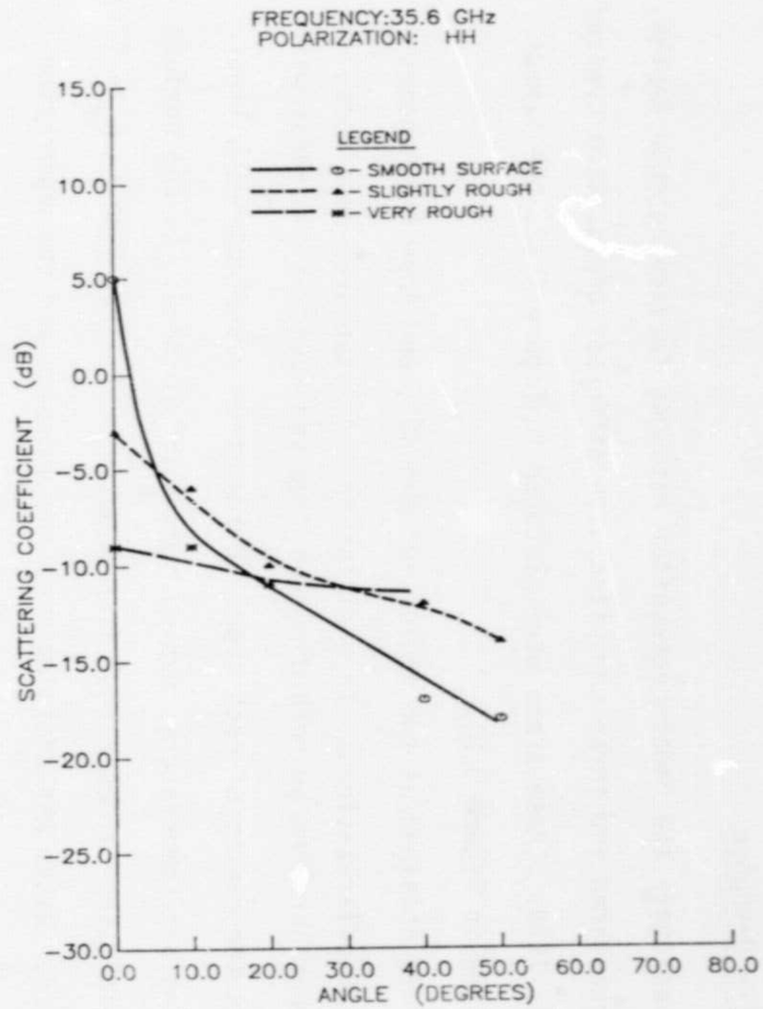


Figure 3.20. The effect of varying artificially induced surface roughness on wet snow at (a) 8.6 GHz, (b) 13.0 GHz, (c) 17.0 GHz, and (d) 35.6 GHz and theoretical model fits for the smooth surface data using a two-scale roughness model [Fung and Eom, 1981] with the listed parameters.


FREQUENCY:17.0 GHz
POLARIZATION: HH
LEGEND
SMOOTH SURFACE
SLIGHTLY ROUGH
VERY ROUGH
Date: 3/19/79
Liquid Water m_v (%): 4.8
Snow Depth (cm): 72
Snow Temperature: 0°C
$kl=1.4$
$kL=60$
$k_E=1.78$
$k_{\rho E}=60$
$\epsilon_v=2.14-j0.45$
SCATTERING COEFFICIENT (dB)
15.0
10.0
5.0
0.0
−5.0
−10.0
−15.0
−20.0
−25.0
−30.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
ANGLE (DEGREES)

(c)


FREQUENCY:35.6 GHz
POLARIZATION: HH
LEGEND
SMOOTH SURFACE
SLIGHTLY ROUGH
VERY ROUGH
SCATTERING COEFFICIENT (dB)
15.0
10.0
5.0
0.0
−5.0
−10.0
−15.0
−20.0
−25.0
−30.0
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
ANGLE (DEGREES)

(d)

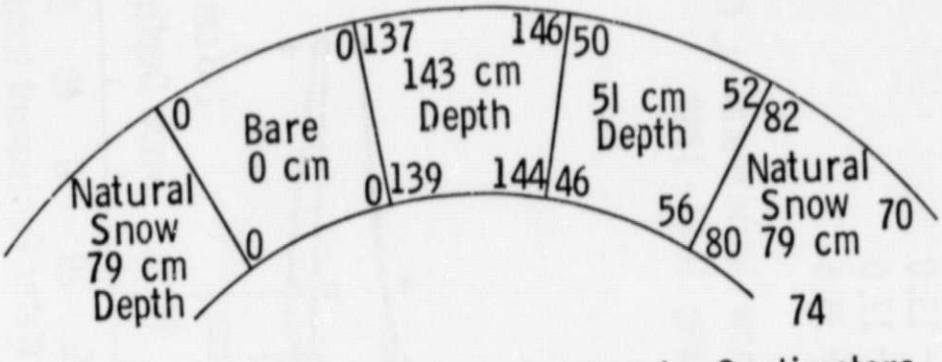
3.3 Snowpile Response

To investigate the radar backscatter response to varying snow depths, a pit was excavated and three snowpiles with different depths were created on March 21, 1979. These areas were pictured in Figure 2.10; the layout is illustrated in Figure 3.21.

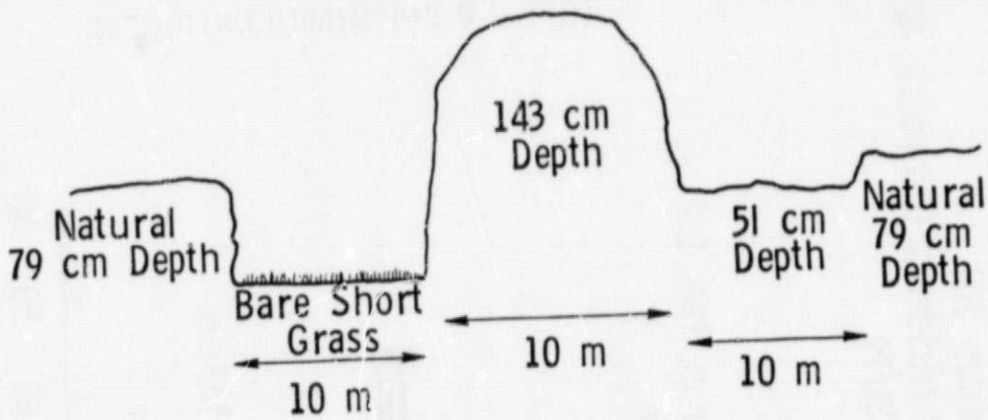
Data were obtained at two angles, 0° and 40°, and four frequencies for HH and HV polarizations. In addition to the "standard" data sets, scan sets were obtained by recording the received power as the radar was moved across the center of each area. The weather was cloudy with light snow fall and air temperatures varied from -0.5° to 3° C. In the surface layer, liquid water values ranged from about m_v = 1.3% at 0800 to m_v = 7.2% at 1645 hours. Water was draining from the snowpack and the underlying short-grass was wet at the start and saturated by the end of the day.

Figure 3.22 illustrates the σ^o variation versus depth for two levels of m_v: 2.2% and 7.2%. The response of σ^o to water equivalent appears to saturate at some value between 0 and 10 cm water equivalent, or at a depth of between 0 and 51 cm, for both m_v cases. Penetration depths have been calculated to be approximately 28 cm, 11 cm, and 2 cm for m_v = 2.2% at 8.6, 17.0 and 35.6 GHz respectively, and for m_v = 7.2%, these values are respectively 13 cm, 4 cm, and 1 cm (Ulaby and Stiles, 1980b). The fact that the σ^o response is essentially constant for snow depths greater than 51 cm is therefore not at all surprising. The small σ^o variations in this region are believed to be due to surface roughness effects. The 0° (nadir) data, although not discussed because of the difficulty of removing fading variations, are given in Appendix B.

In the 1977 experiment, a snowpile data set was acquired for dry snow at 57° angle of incidence. Several measurements were made as a func-



Snow Depths at Corners of Areas in Centimeters
(a)



(b)

Figure 3.21. Layout of the Staurolite snow-drift snowpiles (a) depths on overhead view and (b) profile view.

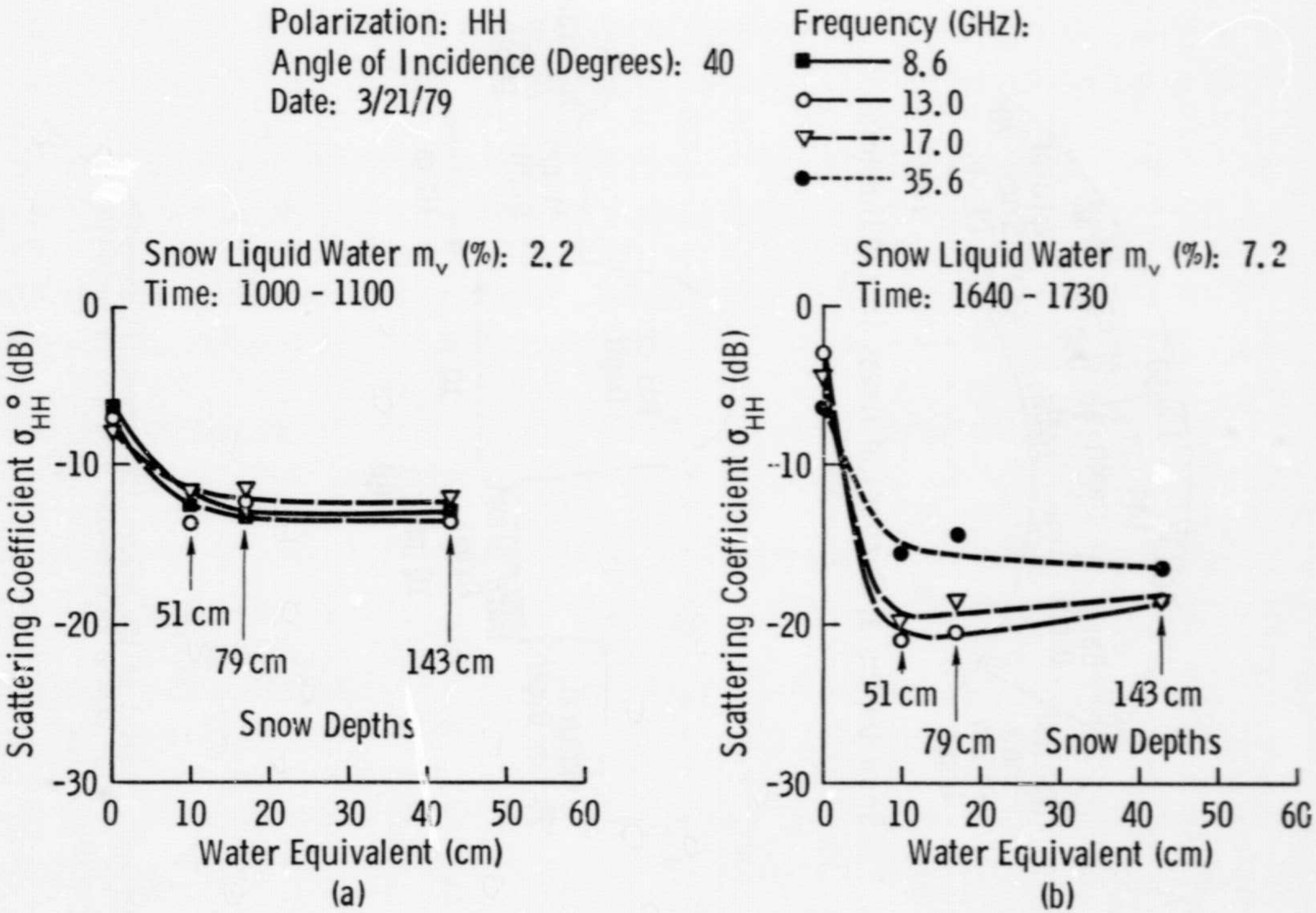


Figure 3.22. Scattering coefficient response to water equivalent at two values of m_v: (a) 2.2% and (b) 7.2%.

tion of water equivalent between 0 (no snow) and a maximum of 71.7 cm. These results, along with the above snowpile data, are plotted for two frequencies in Figure 3.23. It should be noted that the two radar observations were made at somewhat different angles of incidence; in 1977, $\theta = 57°$ while in 1979, $\theta = 40°$. Also, the soil moisture content was 20% by weight in 1977, compared to saturated soil condition (> 50%) for 1979. Nonetheless, it is useful to compare the variation of σ^o with water equivalent for dry snow (1977) with that for wet snow (1979).

At 9 GHz (Figure 3.23a), a difference of 12 dB is observed between σ^o of the slightly wet soil of 1977 (with no snow cover) and the saturated soil of 1979. Relative to the no-snow levels, the addition of dry snow causes an increase in σ^o whereas the addition of wet snow causes a decrease. Beyond about 30 cm of water equivalent, the underlying soil appears to exercise negligible influence on σ^o.

In contrast to the 9 GHz data, at 16.6 GHz (Figure 3.23b), the difference in σ^o between the two years is much smaller for the exposed soil (no snow), but the dynamic range, between σ^o of dry snow and σ^o of the 7.2% water content snow, is much larger for $W \gtrsim 20$ cm. In fact, at $W = 20$ cm, $\sigma^o(0\%) - \sigma^o(7.1\%) \approx 15$ dB. If one were to correct for the difference in the angle of incidence on the basis of other angular observations of σ^o, the above dynamic range would be closer to 17 or 18 dB at $\theta = 40°$.

Figure 3.24 shows an example of the scan data. The received power, which is directly proportional to σ^o, is shown as a function of spatial location as the antenna beam was scanned across the various piles shown in Figure 3.21a. This figure is included mainly to illustrate an alternative data-acquisition technique.

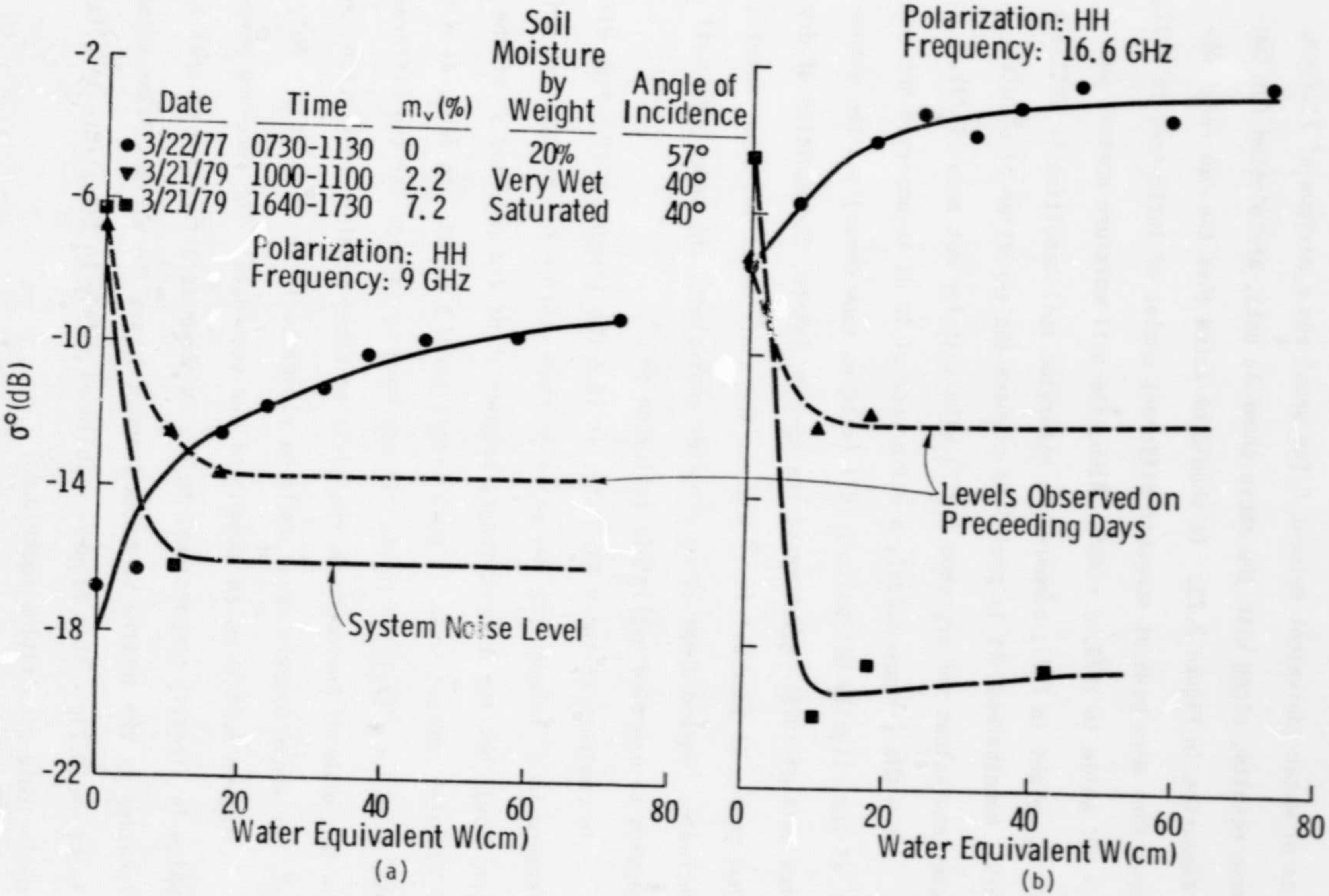


Figure 3.23. Scattering coefficient response to water equivalent for wet and dry snow.

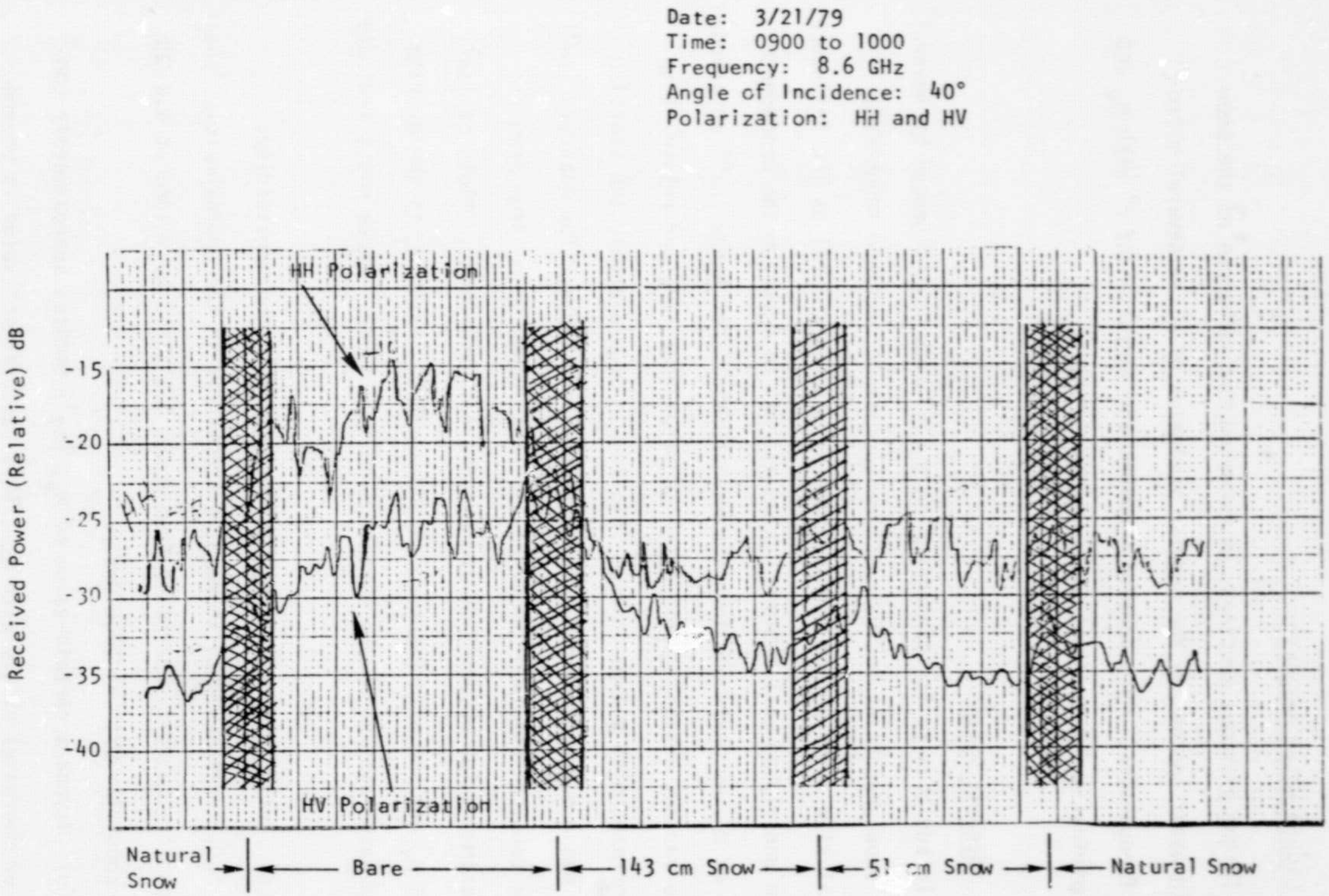


Figure 3.24. An example of x-y plotter scan over the snow pile. Cross-hatched area shows the target transition region.

3.4 Liquid Water Response

In the previous sections, we examined the influence of the snow liquid water content on the angular variation of σ^o at several microwave frequencies. This section examines the variation of σ^o with m_v and an empirical model is developed to relate σ^o to m_v.

3.4.1 Dynamic Range

In addition to its dependence on m_v, σ^o also is influenced by several other snow properties including water equivalent, surface roughness, crystal size distribution and layering structure, as well as the influence of the underlying soil medium. In an attempt to focus on the dependence of σ^o on m_v, we shall consider the magnitude of the change $|\Delta\sigma^o|$ observed in the various diurnal experiments conducted thus far, and relate it to the corresponding change in m_v. That is, in each diurnal, the starting point was a measurement of σ^o for dry snow conditions. The quantity $|\Delta\sigma^o|$ is the total change in σ^o observed due to a change in m_v from zero to the maximum value observed during the diurnal experiment. Plots of $|\Delta\sigma^o|$ versus m_v are shown in Figure 3.25 for $\theta = 50°$. Here, m_v is the average liquid water content of the surface 5 cm snow layer. These plots indicate that:

(a) Prior to "saturation," the magnitude of the sensitivity, $|\Delta\sigma^o/ m_v|$, increases with increasing frequency; in the approximately linear region, this quantity increases from about 1.5 dB/1% by volume at 4.6 GHz up to about 12 dB/1% at 35.6 GHz.

(b) Beyond a certain value of m_v, $|\Delta\sigma^o|$ remains approximately constant or decreases slowly with m_v. This "saturation" value is beyond

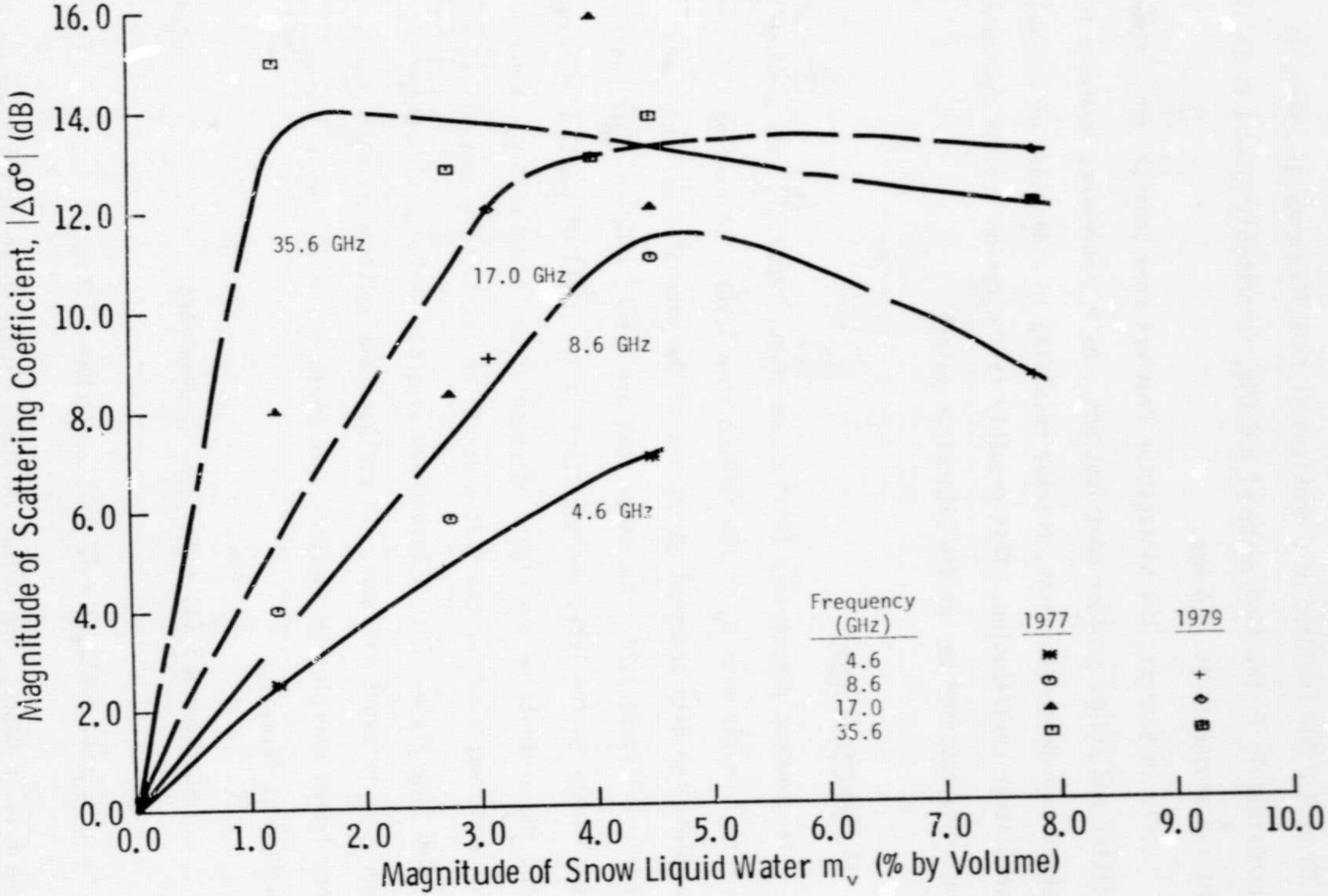


Figure 3.25. Magnitudes of the change in σ° over diurnal periods from 1977 and 1979 as a function of the magnitude of the change in m_v over the same diurnal period.

4.5% at 4.6 GHz (no data were acquired at this frequency in 1979), is approximately in the 4-6% range at 8.6 GHz, is probably around 3% at 17 GHz and around 1% at 35.6 GHz.

(c) In general, the backscatter from wet snow consists of surface scatter and volume scatter contributions. As m_v increases, however, the penetration depth decreases, thereby resulting in a decrease of the volume backscatter contribution. This probably is the reason for the decreasing trend observed beyond the saturation point.

3.4.2 Empirical Model

In previous discussions (Stiles and Ulaby, 1980), σ^o_{dB} was assumed to vary linearly with m_v of the surface snow layer. To examine this assumption, the data acquired during one of the diurnal experiments are plotted in Figure 3.26. Two time-plots are shown, one for $\sigma^o_{dB}(t)$ using the ordinate on the left, and the other is for $m_v(t)$ of the 0-2 cm layer, using the ordinate on the right. Because σ^o decreases with m_v, a negative scale was used for the left ordinate to fascilitate comparisons of the two time-plots. Such a comparison suggests that $\sigma^o_{dB}(t)$ appears to lead $m_v(t)$ by about one hour. To evaluate the validity of this suggestion, linear correlation analyses were performed using the following traditional forms:

$$\sigma^o_{dB}(t) = A\, m_v(t) + B \qquad \text{, unshifted} \qquad (3.5a)$$

$$\sigma^o_{dB}(t) = A' m_v(t + 1) + B' \qquad \text{, time-shifted} \qquad (3.5b)$$

where t is in hours. The values of A and B thus obtained are given in Table 3.4 together with the correlation coefficient ρ associated with the use

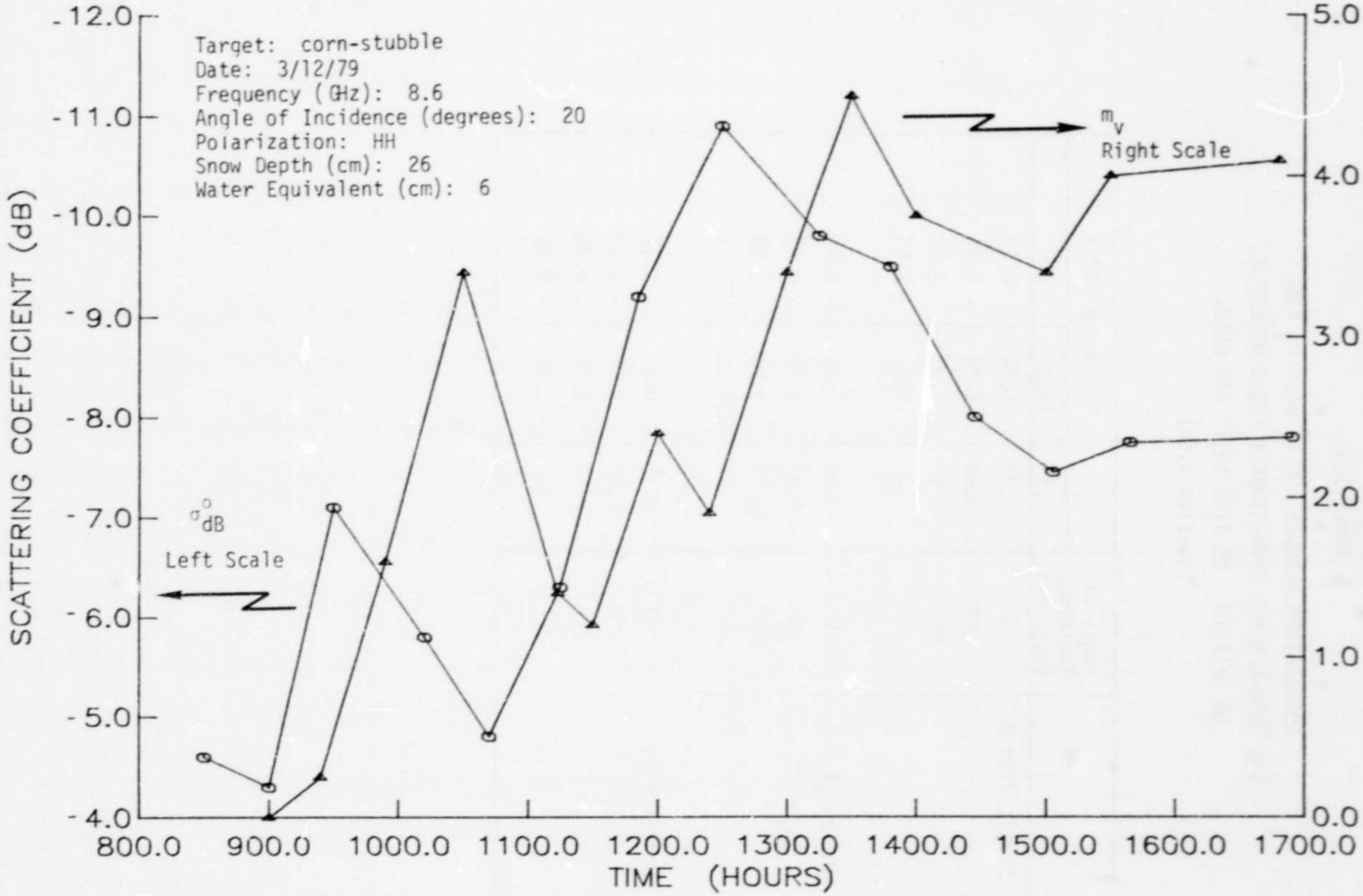


Figure 3.26. Diurnal variation of m_v and σ^o at 8.6 GHz and 20° on an inverted scale for the cornfield illustrating the apparent σ^o response time shift.

TABLE 3.4

CORRELATION RESULTS FOR σ^{o} WITH m_v FOR THE SNOW-COVERED CORN-STUBBLE FIELD OBSERVED ON 3/12/79. NO TIME SHIFT WAS USED. (Equation 3.5a)

	Angle of Incidence (degrees)	Frequency (GHz)		
		8.6	13.0	17.0
Sensitivity A	0°	1.75	1.14	0.24
	20°	- 0.94	- 0.96	- 1.44
	50°	- 1.64	- 2.28	- 2.58
	70°	--	- 2.31	- 2.53
Intercept B	0°	3.84	1.51	5.19
(m_v = 0)	20°	- 5.46	- 5.96	- 4.44
	50°	-10.72	- 9.65	- 7.03
	70°	--	-14.95	-11.41
Correlation	0°	0.75	0.51	0.16
Coefficient	20°	- 0.59	- 0.58	- 0.68
ρ	50°	- 0.81	- 0.78	- 0.79
	70°	--	- 0.69	- 0.69

of the unshifted form given by Equation (3.5a). Similarly, A', B', and ρ are given in Table 3.5 for the time-shifted case defined by Equation (3.5b). Comparison of the two tables shows that for $\theta \gtrsim 20°$, $|\rho|$ is larger for the time-shifted case than for the unshifted case for every frequency/angle of incidence combination; $|\rho|$ varies over the range 0.58 to 0.81 for the unshifted case (Table 3.4), while for the time-shifted case (Table 3.5), its range is between 0.66 and 0.92.

The reason for the time shift is attributed to the difference between the sampling depth of m_v (0-2 cm) and the thickness of the snow surface layer to which the radar response is most sensitive. Since snow melt is the result of absorption of thermal energy from the sun and/or the air above the snow surface, it is suspected that during the snow melting phase, m_v is highest at the surface and decreases with depth. Hence, m_v in the 0-0.5 cm layer, for example, would be much higher than the average measured for the 0-2 cm layer, particularly during the period immediately after the onset of melting.

In addition to the regression analyses performed using Equation (3.5b), others were also performed with time-shifts t_s shorter as well as longer than 1 hour. Slightly different results were obtained for the "optimum" time-shift for different frequencies, but only small improvements in the magnitudes of the correlation coefficients were realized over those obtained with t_s = 1 hour.

The data used in the above discussion were acquired during the diurnal experiment conducted on the snow-covered corn-stubble field on 3/12/79. The maximum value recorded for m_v was 4.5% by value. In contrast, during the 3/16/79 diurnal experiment (SDSU football field), m_v of the 0-2 cm layer reached a peak value of 10.5%, and its rate of change was much faster than that observed during the earlier experiment.

TABLE 3.5

CORRELATION RESULTS FOR σ^o WITH m_v FOR THE SNOW-COVERED CORN-STUBBLE FIELD OBSERVED ON 3/12/79. A ONE HOUR TIME SHIFT WAS USED.

(Equation 3.5b)

	Angle of Incidence (degrees)	Frequency (GHz)		
		8.6	13.0	17.0
Sensitivity A'	0°	1.86	0.82	-0.09
	20°	-1.6	- 1.68	-2.29
	50°	-2.18	- 3.21	-3.55
	70°	---	- 3.36	-3.88
Intercept B' ($m_v = 0$)	0°	3.02	1.92	6.77
	20°	-3.23	- 4.03	-1.56
	50°	-8.57	- 6.23	-3.3
	70°	---	-10.88	-6.39
Correlation Coefficient ρ	0°	0.66	0.3	-0.05
	20°	-0.89	- 0.85	-0.92
	50°	-0.86	- 0.86	-0.86
	70°	---	- 0.77	-0.81

To avoid the use of time-shifts between $\sigma^o(t)$ and $m_v(t)$, and to avoid making the assumption that σ^o_{dB} varies linearly with m_v, it was decided to empirically fit $\sigma^o_{dB}(t)$ to t, and $m_v(t)$ to t, where t is the time referenced to the onset of snowmelt, and then relate σ^o_{dB} to m_v by eliminating the variable t.

The observed temporal variations of $\sigma^o_{dB}(t)$ and $m_v(t)$ with t suggest the following forms:

$$\sigma^o_{dB}(t) = A + B\exp(ct) \tag{3.6}$$

$$m_v(t) = A' + B'\exp(c't) \tag{3.7}$$

where A, B and c are constants for a given frequency/angle of incidence/polarization combination. The fit for $m_v(t)$ is shown in Figure 3.27a, and is given by the expression:

$$m_v(t) = 10.25 - 10.25\exp(-0.615t) \quad , \% \tag{3.8}$$

Figure 3.27b shows examples of empirical fits for $\sigma^o_{dB}(t)$ as a function of t for the different angle/frequency combinations. From these fits, the values of A, B and c were obtained for each set of observation parameters. With all the constants in Equations (3.6) and (3.7) known, the two expressions are manipulated to eliminate t, which leads to

$$\begin{aligned} \sigma^o_{dB} &= A + B\left(\frac{m_v - A'}{-B'}\right)^{c/c'} \\ &= A + B\left(\frac{10.25 - m_v}{10.25}\right)^{c''} \end{aligned} \tag{3.9}$$

where

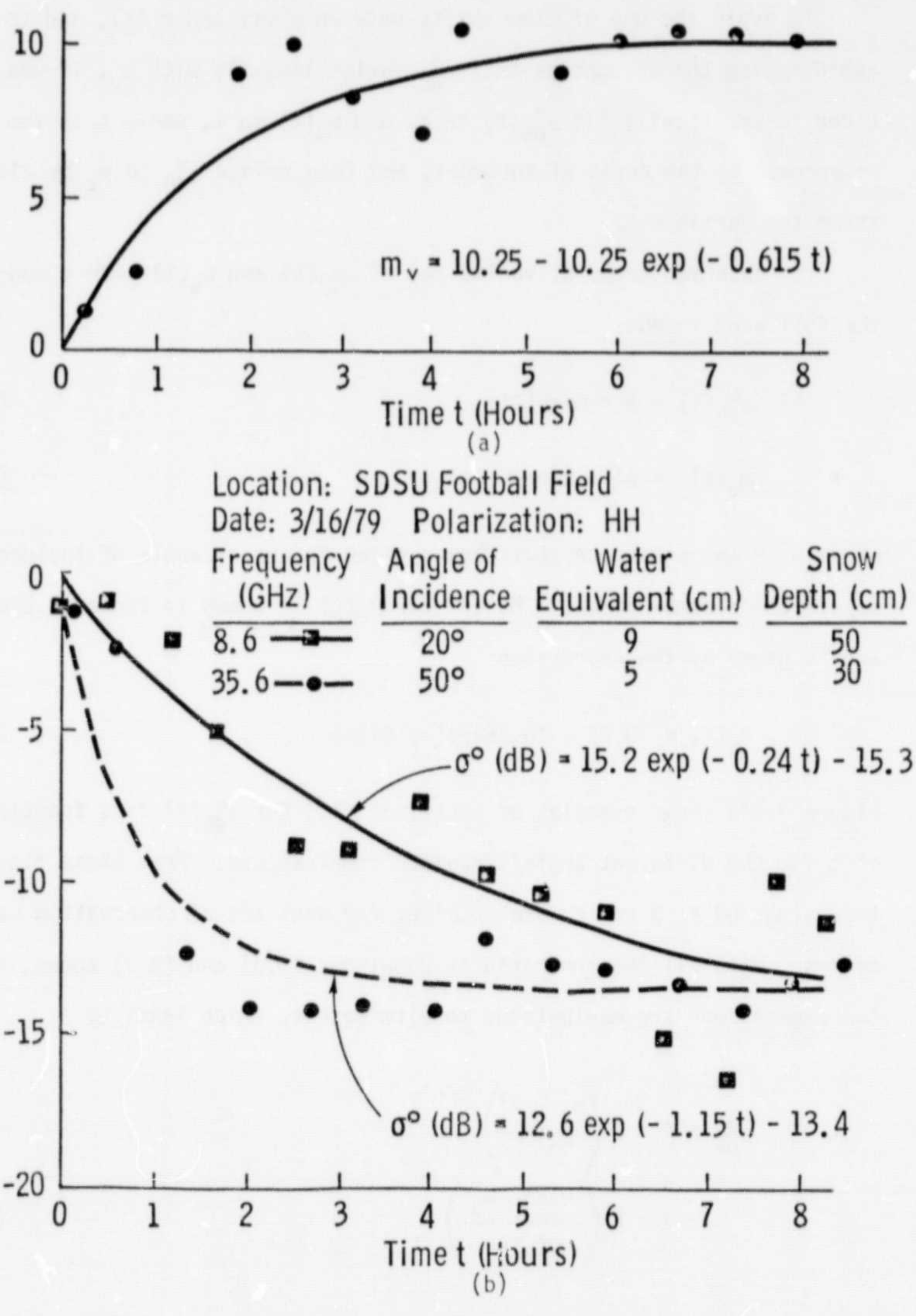
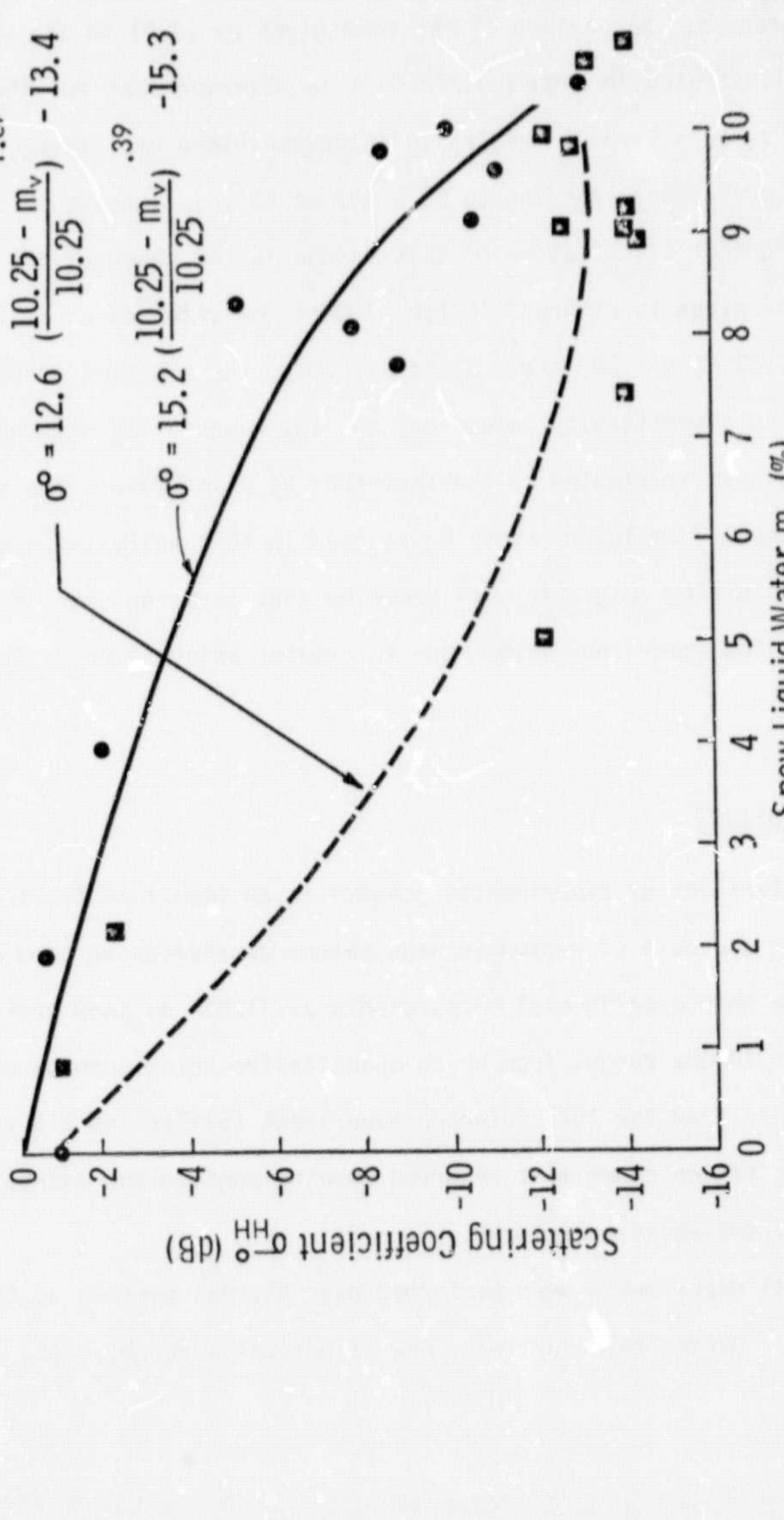


Figure 3.27 Diurnal variation of (a) m_v and (b) σ°(dB) at 8.6 GHz for 20° angle of incidence and at 35.6 GHz for 50° angle of incidence referenced to the onset of snowmelt and (c) the relationship between σ°(dB) and m_v with the time variable removed.


$\sigma^{o} = 12.6\left(\frac{10.25 - m_v}{10.25}\right)^{1.37} - 13.4$
$\sigma^{o} = 15.2\left(\frac{10.25 - m_v}{10.25}\right)^{.39} - 15.3$
Scattering Coefficient σ^{o}_{HH} (dB)
0
-2
-4
-6
-8
-10
-12
-14
-16
0
1
2
3
4
5
6
7
8
9
10
Snow Liquid Water m_v (%)

(c)

$$c'' \triangleq c/c' = -1.626c \tag{3.10}$$

Table 3.6 gives the values of A, B and c" obtained on the basis of the above procedure. Comparison of the form given by (3.9) to the measured data is illustrated in Figure 3.27c. It is observed that for the 8.6 GHz data at 20°, $c'' < 1$ which results in a convex-shaped variation, whereas the other curve corresponding to 35.6 GHz at 50°, is concave in shape with $c'' > 1$. Further illustration of this change in the shape of the σ^o versus m_v curve is given in Figure 3.28 for 17 GHz; the value of c" is 0.80 at $\theta = 20°$, 1.33 at $\theta = 50°$ and 2.03 at $\theta = 70°$. The constant c" may be interpreted as a sensitivity parameter; the increase in its magnitude with increasing θ is attributed to the fact that as θ increases, the slant depth of the 0-2 cm layer (whose m_v is used in this analysis) also increases, resulting in greater influence by that layer on σ^o, and less influence by the lower snow layers due to greater attenuation by the upper layer.

4.0 CONCLUSIONS

Repeatability of experimental results is an important facet of research. In the case of microwave backscatter dependence on snow parameters, the only experimental measurements available on snow backscatter in the 1 to 18 GHz range, from which quantitative relationships could be infered, were from the 1977 Colorado experiment (Stiles and Ulaby, 1980a). The results of the experiment reported herein, confirm and extend the findings of the above experiment.

Several experiments were performed over diurnal pierods at three test sites. During these periods, new situations were observed. On three

TABLE 3.6

COEFFICIENTS FOR THE VARIATION
OF σ^{o} (dB) ON 3/16/79.
(Equation 3.9)

Coefficient	Angle of Incidence (degrees)	Frequency (GHz)			
		8.6	13.0	17.0	35.6
A	20°	-15.3	-12.1	-13.1	-11.7
	50°	--	-22.3	-19.4	-13.4
	70°	--	--	-25.0	-22.2
B	20°	15.2	9.8	12.2	10.8
	50°	--	11.1	14.5	12.6
	70°	--	--	13.4	12.1
c"	20°	0.39	0.57	0.80	1.07
	50°	--	1.14	1.33	1.87
	70°	--	--	2.03	2.86

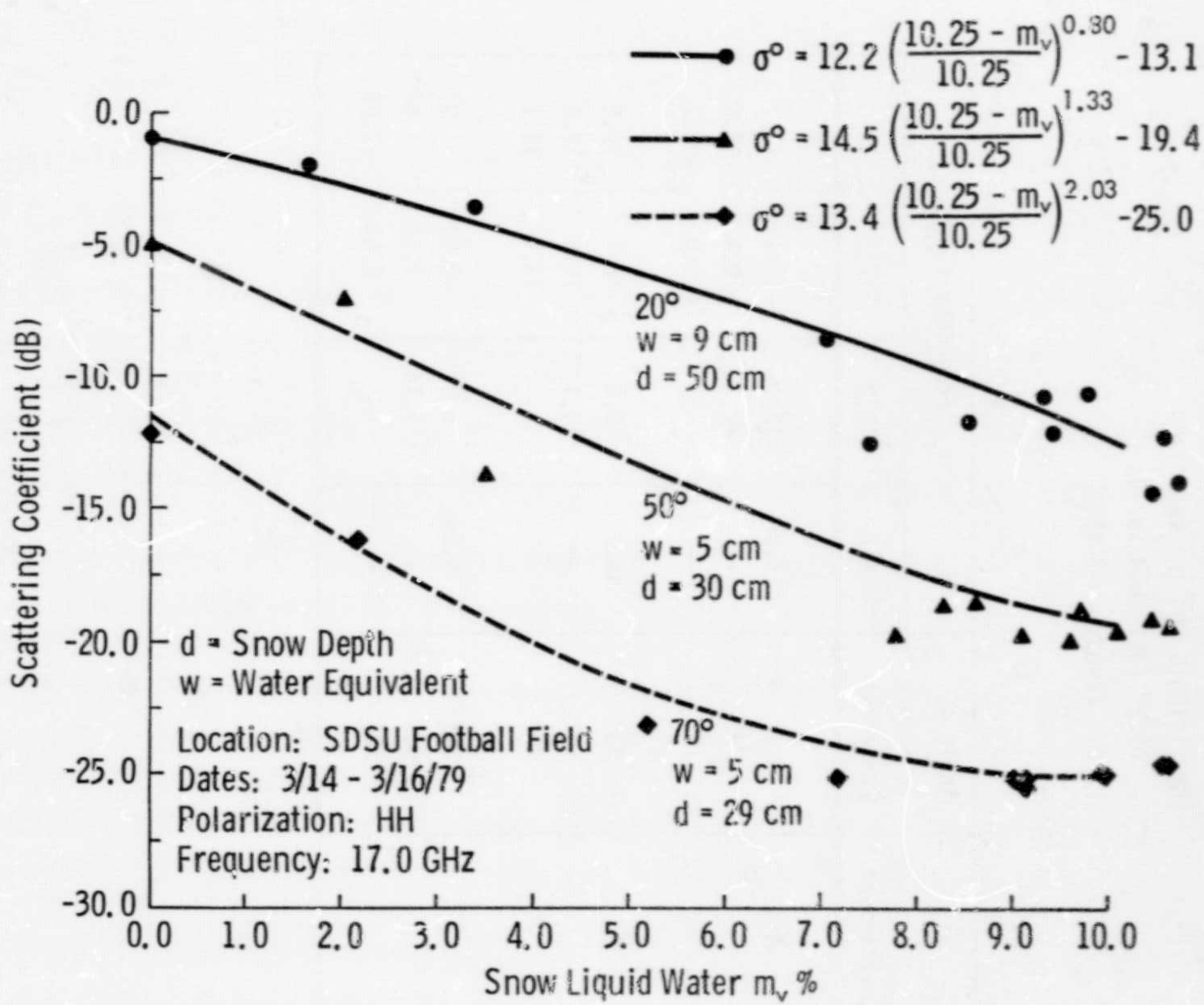


Figure 3.28. The dependence of σ^o on m_v at 17 GHz for three angles of incidence.

days, under below-zero temperature conditions, no liquid water was formed and as a result, the σ^o observations remained essentially constant. The behavior was identical for both clear and overcast conditions. On another day, the snow remained wet with m_v always above 5% by volume. For these conditions, the time-response of σ^o again was constant because of the saturation effects discussed in section 3.4. In addition to the above experiments for which snow conditions remained relatively constant throughout the day, in two other experiments, the liquid water content, and consequently σ^o, varied over a wide range of values. These variations were used to generate an empirical model relating σ^o to m_v.

The effects of surface roughness on the backscatter from snow were examined by comparing measured data to theoretical predictions based on a volume scattering model that incorporates surface roughness at the air-snow interface. Good agreement was obtained between theory and experiment. Also, a surface model was applied to very wet snow.

By combining data acquired for artificially packed wet snow with similar data acquired in 1977 for dry snow, an evaluation was made of the dependence of σ^o on water equivalent for different snow wetness conditions. The observed responses were explained by penetration depth calculations based upon 1977 data.

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APPENDIX A
GROUND-TRUTH DATA

Contents

TABLE A1 [1]

BROOKINGS, SOUTH DAKOTA
SNOW STRATIFICATION, DENSITY AND WATER EQUIVALENT DATA

Date (mm/dd/yr)	Time (Hours)	Layer Code	Layer Top (cm)	Layer Density ρ gm/cm^3	Water Equivalent (cm)
CORN-STUBBLE FIELD					
03/12/79	0830	1	26	0.192	0.385
03/12/79	0830	2	24		
03/12/79	0830	3	17	0.303	0.909
03/12/79	0830	4	14	0.254	3.56
03/12/79	1500	0	26	0.223	5.805
03/12/79	1500	1	26	0.304	0.609
03/12/79	1500	2	24	0.303	1.81
03/12/79	1500	3	18		
03/12/79	1500	4	13	0.254	3.306
03/12/79	1500	0	28	0.167	4.688
STAUROLITE SNOWDRIFT		* (Far-Range 75°)			
03/13/79	0841	1	79	0.404	3.639
03/13/79	0841	2	70	0.338	3.714
03/13/79	0841	3	59	0.395	8.685
03/13/79	0841	4	37		
03/13/79	0841	5	34	0.471	5.180
03/13/79	0841	6	23	0.297	2.080
03/13/79	0841	7	16	0.249	3.985
03/13/79	0841	0	76	0.199	15.141
03/13/79	1300	1*	38		
03/13/79	1300	2*	35		
03/13/79	1300	3*	32		
03/13/79	1300	4*	13		
03/13/79	1300	0*	35	0.128	4.465
SDSU FOOTBALL FIELD		* (Far-Range 50°, 70°)			
03/14/79	0834	1	73	0.313	1.564
03/14/79	0834	2	68		
03/14/79	0834	3	67	0.254	7.883
03/14/79	0834	4	36		
03/14/79	0834	5	35	0.325	5.196
03/14/79	0834	6	19	0.454	8.631
03/14/79	0834	0	69	0.199	13.721
03/14/79	0940	1*	30	0.477	0.953
03/14/79	0940	2*	28	0.237	7.653
03/14/79	0940	0*	31	0.161	4.996

[1] Layer codes are assigned from the snow surface layer downward starting with 1. Layer 0 indicates an overall average (vertical) sample of the snowpack). The layer top (cm) measurements are referenced to the ground level.

TABLE A1 (contd.)

Date (mm/dd/yr)	Time (Hours)	Layer Code	Layer Top (cm)	Layer Density ρ gm/cm³	Water Equivalent (cm)
STAUROLITE SNOWDRIFT					
03/15/79	1015	1	80	0.414	1.241
03/15/79	1015	2	77	0.366	5.127
03/15/79	1015	3	63	0.352	4.223
03/15/79	1015	4	51	0.323	1.617
03/15/79	1015	5	46	0.366	4.760
03/15/79	1015	6	33		
03/15/79	1015	0	76	0.233	17.673
SDSU FOOTBALL FIELD	* (Far-Range 50°, 70°)				
03/16/79	0840	1	70	0.345	1.034
03/16/79	0840	2	67	0.350	10.136
03/16/79	0840	3	38	0.316	6.956
03/16/79	0840	4	16	0.207	3.307
03/16/79	0840	0	65	0.198	12.842
03/16/79	0912	1*	31	0.347	0.694
03/16/79	0912	2*	29		
03/16/79	0912	3*	28	0.290	5.519
03/16/79	0912	4*	9	0.217	1.950
STAUROLITE SNOWDRIFT					
03/17/79	0811	1	73	0.340	0.680
03/17/79	0811	2	71		
03/17/79	0811	3	60	0.364	6.193
03/17/79	0811	4	43	0.458	5.039
03/17/79	0811	5	32	0.315	10.088
03/17/79	0811	0	75	0.236	17.664
03/19/79	0850	1	70	0.419	2.095
03/19/79	0850	2	65	0.496	11.909
03/19/79	0850	3	41	0.500	3.996
03/19/79	0850	4	33	0.388	8.528
03/19/79	0850	5	11	0.358	3.939
03/19/79	0850	0	70	0.308	21.575
03/21/79	0800	0	68	0.362	24.619
03/21/79	0800	0	74	0.291	21.513

TABLE A2*

BROOKINGS, SOUTH DAKOTA
SOIL MOISTURE

Date	Time	Ground Depth (cm)	Wet Weight	Dry Weight	Fraction of Moisture
03/14/79	1115	0-2 2-5	46.0 64.1	34.3 50.7	0.34 0.26
03/15/79	1435	0-2 2-5	38.9 60.7	25.1 43.4	0.55 0.40

*This table presents the soil moisture data obtained during the period when the soil was thawed. The samples were obtained at two depth intervals: 0-2 cm and 2-5 cm. The fraction of moisture was calculated on the basis of weight.

$$\text{fraction moisture} = \frac{\text{wet weight - dry weight}}{\text{dry weight}}$$

SOIL CONDITIONS

F = Frozen, T = Thawed

Location	Date							
	3/12	3/13	3/14	3/15	3/16	3/17	3/19	3/21
Near-Range	F	F	T	T	T	T	T	T
Far-Range	F	F	F	--	F	--	--	--

TABLE A3

BROOKINGS, SOUTH DAKOTA
SNOW TEMPERATURE PROFILE
(°C)

Time	Depth (cm) below Snow Surface								Ground Level	Snow Surface	Air	Other
(Hours)	100	60	40	20	10	6	4	2				
DATE: 03/12/79 CORN-STUBBLE FIELD												
0830	--	--	--	- 3.9	- 6.6	- 7.7	--	- 8.0	- 2.9	- 5.4	--	
0915	--	--	--	- 4.9	- 5.2	- 6.9	--	- 5.0	- 2.4	- 3.4	--	
1000	--	--	--	- 3.9	- 4.2	- 4.4	--	- 1.8	- 2.3	- 1.3	--	
1030	--	--	--	- 3.3	- 4.2	- 2.3	--	- 1.4	- 1.9	- 0.9	--	
1135	--	--	--	- 1.8	- 2.4	- 1.5	--	0.1	- 1.6	0.2	--	
1212	--	--	--	- 1.3	- 0.9	- 0.1	--	0.0	- 0.8	0.1	--	
1252	--	--	--	- 1.4	- 0.8	0.0	--	0.1	- 1.5	0.1	--	
1357	--	--	--	- 1.9	- 1.4	- 0.2	--	0.0	- 1.9	0.1	--	
1437	--	--	--	- 1.6	- 1.2	- 0.2	--	0.0	- 1.8	0.5	--	
1515	--	--	--	- 1.1	- 0.3	- 0.1	--	0.0	- 1.5	0.1	--	
1602	--	--	--	- 1.1	- 0.8	- 0.1	--	0.0	- 1.7	- 0.1	--	
1705	--	--	--	- 1.3	- 0.8	- 0.6	--	- 0.1	- 1.5	- 0.1	--	
DATE: 03/13/79 STAUROLITE SNOWDRIFT												
0841	--	- 2.8	- 2.8	- 2.5	- 2.7	--	- 3.2	- 3.6	- 2.0	- 4.6	--	
1007	--	- 3.1	- 3.3	- 3.1	- 3.5	--	- 4.2	- 4.7	- 2.0	- 5.1	- 6.0	
1102	--	- 4.9	- 3.9	- 3.6	- 4.0	--	- 4.3	- 5.0	- 2.0	- 6.7	--	
1229	--	- 3.9	- 3.7	- 3.7	- 4.3	--	- 4.7	- 4.9	- 2.0	- 6.1	- 8.1	
1348	--	- 5.3	- 4.6	- 4.0	- 4.5	--	- 4.7	- 4.7	- 1.9	- 5.3	- 6.7	
1452	--	- 5.3	- 4.3	- 4.2	- 4.5	--	- 4.7	- 4.9	- 1.9	- 5.6	- 6.3	

TABLE A3 (contd.) - 2

Time (Hours)	Depth (cm) below Snow Surface								Ground Level	Snow Surface	Air	Other
	100	60	40	20	10	6	4	2				
DATE: 03/14/79 SDSU FOOTBALL FIELD												
0842	--	- 2.0	- 2.5	- 4.2	- 5.7	--	- 7.2	- 7.8	- 1.6	- 9.4	-10.4	
0945	--	- 3.0	- 3.2	- 5.6	- 7.3	--	- 8.5	- 9.2	- 2.1	-10.0	-11.0	
0955	--	--	--	- 3.7	- 6.1	--	- 8.1	- 9.1	- 2.9	- 8.8	-11.0	Shallow Snow
1030	--	- 2.9	- 3.2	- 3.2	- 5.8	--	- 7.2	- 8.1	- 2.3	- 8.8	-11.4	
1105	--	- 2.9	- 3.4	- 3.4	- 6.1	--	- 6.9	- 7.3	- 2.2	- 7.3	-11.6	
1215	--	- 4.9	- 5.0	- 5.0	- 5.8	--	- 6.1	- 6.6	- 2.2	- 8.1	-10.6	
1307	--	- 2.3	- 2.9	- 2.9	- 4.6	--	- 6.2	- 6.0	- 2.1	- 6.0	-10.3	
1330	--	--	--	- 2.8	- 3.1	--	- 2.4	- 3.0	- 3.0	- 4.3	-11.3	Shallow Snow
1415	--	- 2.9	- 3.3	- 4.4	- 4.5	--	- 5.2	- 5.7	- 2.1	--	-11.3	
1500	--	- 3.2	- 3.7	- 4.3	- 4.5	--	- 5.7	- 7.6	- 2.1	- 7.7	-11.1	
1540	--	- 3.2	- 3.4	- 4.9	- 6.3	--	- 7.5	- 7.8	- 2.3	- 7.4	-12.5	
DATE: 03/15/79 STAUROLITE SNOWDRIFT												
1015	--	- 4.8	- 7.1	-13.8	-13.9	--	-14.2	-12.1	- 2.1	- 8.6	-12.0	
1116	--	- 4.4	- 6.9	-11.8	-11.9	--	- 9.1	- 7.8	- 1.5	- 8.3	- 7.6	
1216	--	- 2.2	- 4.0	- 9.4	- 9.7	--	- 6.5	- 5.3	- 0.4	- 5.6	- 6.0	
1318	--	- 2.9	- 5.5	- 9.5	- 8.6	--	- 6.9	- 4.2	- 0.4	- 3.5	- 3.7	
1412	--	- 3.7	- 6.4	- 9.3	- 7.5	--	- 3.9	- 3.5	- 0.2	- 2.3	- 2.7	
1530	--	- 2.5	- 4.4	- 6.7	- 5.2	--	- 4.1	- 2.8	- 0.3	- 3.1	- 3.4	
DATE: 03/16/79 SDSU FOOTBALL FIELD												
0856	--	- 0.5	- 2.2	- 4.0	- 4.1	--	- 2.4	- 1.3	0.9	0.8	1.5	
0915	--	--	--	- 2.1	- 2.5	--	- 1.4	- 0.1	- 0.7	1.0	1.0	Shallow Snow
0950	--	- 0.7	- 2.4	- 4.0	- 3.7	--	- 1.2	- 0.2	1.1	1.0	2.0	
1000	--	--	--	1.3	- 1.7	--	- 0.5	- 0.2	- 0.7	1.1	2.2	Shallow Snow
1133	--	- 0.6	- 2.3	- 3.3	- 1.9	--	1.2	1.2	1.1	1.3	3.6	
1230	--	0.8	- 1.0	- 1.8	2.0	--	1.0	1.1	1.1	1.5	4.1	
1250	--	--	--	- 0.4	- 0.2	--	1.0	1.0	- 0.4	1.1	3.7	Shallow Snow
1410	--	- 0.3	- 1.1	- 1.2	1.3	--	1.3	1.4	1.1	1.6	4.8	
1420	--	--	--	0.8	0.8	--	1.0	1.1	- 0.5	1.2	4.1	Shallow Snow

TABLE A3 (contd.) - 3

Time	Depth (cm) below Snow Surface								Ground	Snow		
(Hours)	100	60	40	20	10	6	4	2	Level	Surface	Air	Other
(DATE: 03/16/79 - contd.)												
1510	--	- 0.1	- 0.8	- 0.7	1.0	--	1.0	1.1	1.2	1.2	3.4	
1525	--	--	--	0.8	0.7	--	0.8	0.9	- 0.2	1.1	2.9	Shallow Snow
1600	--	--	--	0.9	0.9	--	1.0	1.0	- 0.3	1.1	3.4	Shallow Snow
1610	--	- 0.2	- 0.6	- 0.6	0.9	--	1.0	1.2	1.1	1.2	3.0	
1650	--	- 0.3	- 1.0	- 0.4	- 0.7	--	- 0.7	- 0.7	0.6	0.8	3.0	
DATE: 03/17/79 STAUROLITE SNOWDRIFT												
0811	--	0.9	1.0	1.0	1.0	--	1.0	0.9	0.9	1.1	2.4	
0936	--	1.1	1.1	1.1	1.2	--	1.2	1.2	1.0	1.6	3.0	
1207	--	1.0	1.2	1.2	1.2	--	1.3	1.1	1.1	2.0	3.5	
1414	--	1.4	1.5	1.6	1.7	--	1.8	1.5	1.5	2.2	5.0	
1625	--	1.2	1.4	1.4	1.5	--	1.5	1.3	1.3	2.0	4.5	
DATE: 03/19/79 STAUROLITE SNOWDRIFT												
0855	--	1.0	1.0	1.0	1.0	--	0.9	1.1	1.0	1.7	2.0	
DATE: 03/21/79 STAUROLITE SNOWDRIFT												
0800	0.1* 1.2	1.2	1.2	1.2	1.2	--	1.2	0.2	0.0	0.3	2.9	
0823	- 0.2	- 0.2	- 0.2	- 0.2	- 0.2	--	- 0.4	- 0.4	- 0.2	- 0.4	- 0.5	
1030	0.0	0.0	0.0	0.0	0.0	--	0.0	0.0	0.0	0.0	1.3	

*140 cm depth

Note: Positive values of snow temperature were "measured" and may be the result of thermometer calibration.

TABLE A4 [2]

BROOKINGS, SOUTH DAKOTA
LIQUID WATER m_v (%)

Date (mm/dd/yr)	Time (Hours)	Layer Code	Snow Temperature (°C)	Liquid Water m_v (% by volume)
CORN-STUBBLE FIELD				
03/12/79	0800	1	0.	0.
03/12/79	0830	1	-5.3	0.
03/12/79	0900	1	-5.4	0.
03/12/79	0930	1	-5.0	0.235
03/12/79	0950	2	-5.0	0.180
03/12/79	1000	1	-5.0	1.606
03/12/79	1030	1	0.	3.486
03/12/79	1035	2	0.	0.858
03/12/79	1100	2	-2.2	0.
03/12/79	1115	1	0.	1.312
03/12/79	1130	1	1.1	1.156
03/12/79	1200	1	1.6	2.414
03/12/79	1245	2	-1.4	1.060
03/12/79	1300	1	-1.7	3.358
03/12/79	1315	2	0.	2.296
03/12/79	1330	1	-1.2	4.546
03/12/79	1400	1	-1.7	3.795
03/12/79	1500	1	2.0	3.440
03/12/79	1505	2	0.	0.
03/12/70	1530	1	-1.2	3.997
03/12/79	1600	1	-1.4	2.611
03/12/79	1620	2	0.	0.046
03/12/79	1630	1	-1.3	3.398
03/12/79	1700	1	-1.6	2.972
STAUROLITE SNOWDRIFT				
03/13/79	0900	1	0.	0.
03/13/79	0930	1	-4.8	0.
03/13/79	1000	1	-6.3	0.
03/13/79	1035	1	-7.2	0.
03/13/79	1105	0	-5.0	0.
03/13/79	1255	1	-5.7	0.
03/13/79	1310	0	-6.5	0.
03/13/79	1405	0	-7.2	0.
03/13/79	1520	1	-5.5	0.

[2] Layer codes in this table correspond to the following depths from the surface downward: 1-0 to 2 cm, 2-2 to 5 cm, 3-5 to 10 cm, 4-10-15 cm, 5-15 to 20 cm, etc.

TABLE A4 (contd.) -2

Date (mm/dd/yr)	Time (Hours)	Layer Code	Snow Temperature (°C)	Liquid Water m_v (% by volume)
SDSU FOOTBALL FIELD				
03/14/79	0830	1	0.	0.
03/14/79	0900	1	-15.0	0.
03/14/79	0945	1	-13.8	0.
03/14/79	1030	1	- 9.5	0.
03/14/79	1114	1	-10.0	0.
03/14/79	1250	1	-10.4	0.
03/14/79	1330	1	- 9.7	0.
03/14/79	1400	1	-10.9	0.
03/14/79	1430	1	-11.9	0.
03/14/79	1505	1	-11.2	0.
03/14/79	1540	1	-11.0	0.
STAUROLITE SNOWDRIFT				
03/15/79	0905	1	-14.8	0.
03/15/79	1000	1	-12.9	0.
03/15/79	1030	1	- 7.3	0.
03/15/79	1100	1	- 5.2	0.
03/15/79	1140	1	- 7.3	0.
03/15/79	1215	1	- 8.5	0.
03/15/79	1245	1	- 5.4	0.
03/15/79	1335	1	- 5.5	0.
03/15/79	1415	1	- 5.7	0.
03/15/79	1515	1	- 9.9	0.
03/15/79	1600	1	- 9.3	0.
SDSU FOOTBALL FIELD				
03/16/79	0840	1	- 0.4	1.281
03/16/79	0920	1	- 1.3	2.556
03/16/79	1025	2	- 1.0	1.333
03/16/79	1030	1	- 1.0	9.151
03/16/79	1100	1	- 1.5	10.052
03/16/79	1130	1	- 0.5	8.366
03/16/79	1215	1	- 0.5	6.848
03/16/79	1215	2	- 0.5	3.536
03/16/79	1230	3	- 0.7	0.077
03/16/79	1250	1	- 1.0	10.500
03/16/79	1319	2	0.	5.002
03/16/79	1336	3	0.	2.151
03/16/79	1355	1	0.	9.022
03/16/79	1421	2	0.	5.128
03/16/79	1435	1	0.	10.144
03/16/79	1444	3	0.	0.830
03/16/79	1505	1	0.	10.500

(cont'd.)

Date (mm/dd/yr)	Time (Hours)	Layer Code	Snow Temperature (°C)	Liquid Water m_v (% by volume)
03/16/79	1540	1	0.	10.500
03/16/79	1608	2	0.	6.108
03/16/79	1625	4	0.	7.801
03/16/79	1640	4	0.	9.229
03/16/79	1650	1	0.	4.946
03/16/79	1650	2	0.	6.609
STAUROLITE SNOWDRIFT				
03/17/79	0810	1	0.	9.603
03/17/79	0915	1	0.	10.200
03/17/79	0949	2	0.	3.511
03/17/79	1000	4	0.	4.389
03/17/79	1035	1	0.	9.563
03/17/79	1101	5	0.	5.785
03/17/79	1120	7	0.	13.740
03/17/79	1140	6	0.	1.863
03/17/79	1205	8	0.	4.206
03/17/79	1215	2	0.	10.800
03/17/79	1230	1	0.	7.266
03/17/79	1335	1	0.	5.688
03/19/79	0915	1	0.	4.843
03/19/79	1129	1	0.	1.168
03/21/79	0800	1	0.	1.293
03/21/79	0800	2	0.	0.760
03/21/79	0835	1	- 0.5	1.711
03/21/79	0835	2	- 0.5	0.
03/21/79	0935	1	0.	0.843
03/21/79	0905	2	0.	0.
03/21/79	1007	2	0.	2.752
03/21/79	1007	1	0.	2.452
03/21/79	1100	1	0.	2.023
03/21/79	1100	2	0.	3.712
03/21/79	1123	1	0.	2.267
03/21/79	1123	2	0.	2.204
03/21/79	1410	1	0.2	5.746
03/21/79	1410	2	0.2	4.264
03/21/79	1410	3	0.2	3.199
03/21/79	1448	5	0.2	3.118
03/21/79	1448	9	0.2	3.960
03/21/79	1448	0	0.2	6.335
03/21/79	1529	0	0.2	5.227
03/21/79	1529	0	0.2	6.817
03/21/79	1615	1	0.	5.495
03/21/79	1615	2	0.	3.845
03/21/79	1645	1	0.	7.220
03/21/79	1645	2	0.	2.873

APPENDIX B

Scattering Coefficient Data

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMAO (dB)
CORN FIELD

DATE 3/12/79

FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6

ANGLE = 0 DEGREES RANGE 20.0714 TIME 816

HH	4.87	5.49	5.99	
HV	-3.16	-2.92	-0.79	

ANGLE = 20 DEGREES RANGE 21.0833 TIME 825

HH	-4.79	-6.67	-4.78	
HV	-10.72	-13.08	-10.90	

ANGLE = 50 DEGREES RANGE 32.9425 TIME 834

HH	-11.13	-10.51	-7.67	
HV	-17.74	-16.12	-12.40	

ANGLE = 70 DEGREES RANGE 63.0826 TIME 839

HH	-14.52	-13.68	-9.35	
HV	-20.32	-19.22	-14.45	

ANGLE = 0 DEGREES RANGE 19.8636 TIME 845

HH	5.73	3.51	7.65	
HV	-2.16	-3.42	0.06	

ANGLE = 20 DEGREES RANGE 21.5253 TIME 858

HH	-4.29	-6.31	-5.12	
HV	-9.87	-11.52	-10.08	

ANGLE = 50 DEGREES RANGE 33.0185 TIME 910

HH	-10.49	-9.66	-7.80	
HV	-17.72	-14.96	-12.69	

ANGLE = 70 DEGREES RANGE 63.9428 TIME 913

HH	-15.07	-13.53	-9.92	
HV	-21.17	-18.37	-16.02	

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMAO (dB)
CORN FIELD

DATE 3/12/79

FREQUENCY (GHZ)

ANGLE = 0 DEGREES   RANGE 18.6361   TIME 922

	8.6	13.0	17.0	35.6
HH	3.35		4.16	
HV	-4.91	-8.13	-1.91	

ANGLE = 20 DEGREES   RANGE 22.9490   TIME 932

	8.6	13.0	17.0	35.6
HH	-7.07	-4.74	-5.39	
HV	-13.75	-9.73	-10.07	

ANGLE = 50 DEGREES   RANGE 33.1235   TIME 942

	8.6	13.0	17.0	35.6
HH	-12.46	-10.71	-7.49	
HV	-18.26	-15.73	-12.50	

ANGLE = 70 DEGREES   RANGE 60.3518   TIME 949

	8.6	13.0	17.0	35.6
HH	-15.22	-13.73	-11.26	
HV	-20.71	-19.48	-16.75	

ANGLE = 0 DEGREES   RANGE 20.2352   TIME 958

	8.6	13.0	17.0	35.6
HH	4.75	3.76	6.43	
HV	-3.53	-2.02	-1.18	

ANGLE = 20 DEGREES   RANGE 21.9144   TIME 1007

	8.6	13.0	17.0	35.6
HH	-5.80	-5.44	-3.56	
HV	-10.39	-10.84	-9.86	

ANGLE = 50 DEGREES   RANGE 32.1392   TIME 1017

	8.6	13.0	17.0	35.6
HH	-11.09	-10.05	-7.63	
HV	-17.56	-17.77	-13.09	

ANGLE = 70 DEGREES   RANGE 57.8421   TIME 1024

	8.6	13.0	17.0	35.6
HH	-14.42	-15.23	-11.74	
HV	-20.43	-21.76	-17.40	

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMAO (dB)
CORN FIELD

DATE 3/12/79

FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6

ANGLE = 0 DEGREES RANGE 20.1636 TIME 1031

HH	6.43	3.03	7.48	
HV	-1.42	-3.49	-2.53	

ANGLE = 20 DEGREES RANGE 21.6883 TIME 1043

HH	-4.78	-4.73	-4.20	
HV	-8.97	-12.61	-11.35	

ANGLE = 50 DEGREES RANGE 33.3516 TIME 1051

HH	-11.94	-11.35	-8.50	
HV	-18.05	-17.25	-13.33	

ANGLE = 70 DEGREES RANGE 58.0590 TIME 1057

HH	-15.38	-17.27	-13.18	
HV	-20.63	-22.91	-19.59	

ANGLE = 20 DEGREES RANGE 21.9266 TIME 1114

HH	-6.25	-7.21	-6.48	
HV	-10.79	-12.28	-13.21	

ANGLE = 50 DEGREES RANGE 32.2894 TIME 1124

HH	-13.52	-13.28	-11.76	
HV	-19.23	-19.82	-16.62	

ANGLE = 70 DEGREES RANGE 58.5711 TIME 1132

HH	-18.10	-23.49	-20.55	
HV	-23.99	-27.45	-24.99	

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMAO (dB)
CORN FIELD

DATE 3/12/79

FREQUENCY (GHZ)

ANGLE = 0 DEGREES RANGE 20.0217 TIME 1145

	8.6	13.0	17.0	35.6
HH	7.78	2.14	5.31	
HV	-0.78	-4.90	-3.63	

ANGLE = 20 DEGREES RANGE 22.4722 TIME 1156

	8.6	13.0	17.0	35.6
HH	-9.22	-9.05	-10.43	
HV	-14.00	-16.20	-16.53	

ANGLE = 50 DEGREES RANGE 33.3645 TIME 1204

	8.6	13.0	17.0	35.6
HH	-15.61	-15.86	-14.19	
HV	-22.43	-22.51	-20.49	

ANGLE = 70 DEGREES RANGE 61.9891 TIME 1209

	8.6	13.0	17.0	35.6
HH		-23.33	-21.56	
HV	-23.35	-29.19	-28.18	

ANGLE = 20 DEGREES RANGE 22.4935 TIME 1231

	8.6	13.0	17.0	35.6
HH	-10.95	-12.27	-11.26	
HV	-17.13	-17.34	-17.76	

ANGLE = 50 DEGREES RANGE 32.4071 TIME 1241

	8.6	13.0	17.0	35.6
HH	-17.17	-20.74	-18.[illegible]	
HV	-23.65	-25.88	-25.12	

ANGLE = 70 DEGREES RANGE 60.4719 TIME 1247

	8.6	13.0	17.0	35.6
HH		-25.57	-22.98	
HV	-23.55	-29.35	-29.38	

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMAO (dB)
CORN FIELD

DATE 3/12/79

FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6
ANGLE = 0 DEGREES	RANGE 19.8102	TIME 1259		
HH	11.61	7.52	7.43	
HV	2.17	-0.50	-1.38	
ANGLE = 20 DEGREES	RANGE 22.3073	TIME 1315		
HH	-9.81	-11.64	-9.94	
HV	-14.25	-17.21	-16.71	
ANGLE = 50 DEGREES	RANGE 32.9568	TIME 1324		
HH	-18.99	-20.33	-19.32	
HV	-25.07	-24.87	-24.91	
ANGLE = 70 DEGREES	RANGE 57.0598	TIME 1332		
HH		-23.36	-20.65	
HV	-24.42	-29.49	-28.50	
ANGLE = 0 DEGREES	RANGE 20.0374	TIME 1338		
HH	11.71	7.46	8.91	
HV	2.29	1.40	0.03	
ANGLE = 20 DEGREES	RANGE 22.0424	TIME 1350		
HH	-9.53	-10.28	-10.92	
HV	-14.67	-15.37	-15.67	
ANGLE = 50 DEGREES	RANGE 32.7664	TIME 1401		
HH	-18.03	-19.95	-17.86	
HV	-24.28	-24.17	-23.37	
ANGLE = 70 DEGREES	RANGE 61.1851	TIME 1407		
HH		-24.30	-22.40	
HV	-23.66	-28.92	-27.96	

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMAO (dB)
CORN FIELD

DATE 3/12/79

FREQUENCY (GHZ)

ANGLE = 0 DEGREES RANGE 19.8379 TIME 1414

	8.6	13.0	17.0	35.6
HH	11.65	6.88	5.96	
HV	1.56	-0.52	-0.48	

ANGLE = 20 DEGREES RANGE 22.2611 TIME 1428

	8.6	13.0	17.0	35.6
HH	-7.94	-9.85	-8.61	
HV	-13.70	-14.63	-15.59	

ANGLE = 50 DEGREES RANGE 32.6666 TIME 1436

	8.6	13.0	17.0	35.6
HH	-16.74	-18.46	-16.69	
HV	-23.50	-24.63	-23.80	

ANGLE = 70 DEGREES RANGE 58.4238 TIME 1441

	8.6	13.0	17.0	35.6
HH		-24.54	-21.31	
HV	-24.30	-28.17	-27.11	

ANGLE = 0 DEGREES RANGE 20.3970 TIME 1450

	8.6	13.0	17.0	35.6
HH	12.17	7.84	6.06	
HV	1.69	0.66	-1.85	

ANGLE = 20 DEGREES RANGE 22.3831 TIME 1504

	8.6	13.0	17.0	35.6
HH	-7.41	-9.08	-9.47	
HV	-13.28	-14.48	-15.85	

ANGLE = 50 DEGREES RANGE 33.4293 TIME 1512

	8.6	13.0	17.0	35.6
HH	-16.28	-17.26	-16.19	
HV	-22.81	-23.32	-22.66	

ANGLE = 70 DEGREES RANGE 59.6977 TIME 1516

	8.6	13.0	17.0	35.6
HH		-23.34	-20.09	
HV	18.02	-29.07	-27.35	

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMAO (dB)
CORN FIELD

DATE 3/12/79

FREQUENCY (GHZ)

ANGLE = 0 DEGREES RANGE 19.9073 TIME 1522

	8.6	13.0	17.0	35.6
HH	9.54	4.24	3.33	
HV	-0.03	-2.63	-4.27	

ANGLE = 20 DEGREES RANGE 22.3874 TIME 1537

	8.6	13.0	17.0	35.6
HH	-7.81	-8.46	-10.13	
HV	-14.06	-14.15	-15.67	

ANGLE = 50 DEGREES RANGE 32.7759 TIME 1545

	8.6	13.0	17.0	35.6
HH	-15.49	-16.29	-15.45	
HV	-22.52	-23.19	-21.59	

ANGLE = 70 DEGREES RANGE 58.0919 TIME 1554

	8.6	13.0	17.0	35.6
HH		-23.85	-20.97	
HV	-24.06	-28.56	-3.87	

ANGLE = 0 DEGREES RANGE 20.0032 TIME 1601

	8.6	13.0	17.0	35.6
HH	7.71	3.13	2.45	
HV	0.91	-3.63	-4.45	

ANGLE = 20 DEGREES RANGE 23.1986 TIME 1615

	8.6	13.0	17.0	35.6
HH	-11.67	-9.28	-11.14	
HV	-18.62	-15.63	-17.22	

ANGLE = 50 DEGREES RANGE 32.8669 TIME 1623

	8.6	13.0	17.0	35.6
HH	-16.61	-16.61	-15.89	
HV	-24.31	-23.75	-21.92	

ANGLE = 70 DEGREES RANGE 60.6290 TIME 1628

	8.6	13.0	17.0	35.6
HH		-22.81	-20.33	
HV	-26.98	-28.35	-26.52	

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMAO (dB)
CORN FIELD

DATE 3/12/79

FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6
ANGLE = 0 DEGREES	RANGE 19.9391	TIME 1634		
HH	8.98	1.03	0.67	
HV	-4.62	-6.72	-7.34	
ANGLE = 20 DEGREES	RANGE 22.1777	TIME 1649		
HH	-7.82	-8.77	-10.95	
HV	-15.88	-16.11	-15.73	
ANGLE = 50 DEGREES	RANGE 34.0229	TIME 1657		
HH	-18.29	-17.69	-17.60	
HV	-26.04	-24.13	-23.23	
ANGLE = 70 DEGREES	RANGE 55.8380	TIME 1702		
HH		-24.68	-21.68	
HV	-26.29	-29.34	-26.99	

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMA0 (dB)
SDSU FOOTBALL FIELD

DATE 3/14/79

FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6
ANGLE = 0 DEGREES		RANGE 20.0918		TIME 809
HH	6.77	4.85	6.22	5.73
HV	-0.08	-4.95	-1.33	-3.42
ANGLE = 20 DEGREES		RANGE 21.6683		TIME 825
HH	-0.78	-2.55	-0.91	-1.35
HV	-5.47	-9.72	-6.29	-3.41
ANGLE = 50 DEGREES		RANGE 31.0840		TIME 833
HH	-13.42	-11.48	-5.06	-1.00
HV	-19.59	-16.58	-10.44	-3.52
ANGLE = 70 DEGREES		RANGE 53.2848		TIME 840
HH		-18.81	-12.00	-10.37
HV	-26.04	-24.10	-16.85	-12.78
ANGLE = 0 DEGREES		RANGE 20.0656		TIME 851
HH	8.07	4.49	5.94	5.08
HV	-0.19	-3.60	-0.92	-5.53
ANGLE = 20 DEGREES		RANGE 21.4467		TIME 906
HH	0.77	-2.47	0.76	0.05
HV	-5.22	-8.86	-6.09	-3.74
ANGLE = 50 DEGREES		RANGE 30.9621		TIME 913
HH	-13.70	-10.85	-6.33	-1.29
HV	-20.55	-16.85	-11.97	-6.03
ANGLE = 70 DEGREES		RANGE 53.1227		TIME 923
HH		-15.27	-9.56	-8.68
HV	-24.48	-22.16	-15.25	-11.54

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMAO (dB)
SDSU FOOTBALL FIELD

DATE 3/14/79

FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6
ANGLE = 0 DEGREES RANGE 19.5557 TIME 932				
HH	7.26	0.98	4.69	7.12
HV	0.04	-6.02	-2.57	-3.27
ANGLE = 20 DEGREES RANGE 21.0719 TIME 943				
HH	0.64	-2.88	-0.63	-0.26
HV	-4.13	-10.39	-6.77	-5.10
ANGLE = 50 DEGREES RANGE 30.1868 TIME 951				
HH	-13.66	-12.14	-5.83	-0.49
HV	-20.28	-17.97	-12.40	-4.97
ANGLE = 70 DEGREES RANGE 53.4311 TIME 958				
HH		-16.56	-11.81	-8.38
HV	-25.33	-23.57	-16.74	-12.02
ANGLE = 0 DEGREES RANGE 19.8973 TIME 1004				
HH	6.68	3.57	5.41	4.56
HV	1.22	-3.96	-1.38	-5.11
ANGLE = 20 DEGREES RANGE 21.3646 TIME 1018				
HH	1.05	-2.20	0.44	-1.09
HV	-4.00	-7.07	-5.37	-4.93
ANGLE = 50 DEGREES RANGE 30.2950 TIME 1026				
HH	-13.59	-11.63	-6.31	-1.83
HV	-20.01	-16.10	-11.87	-5.11
ANGLE = 70 DEGREES RANGE 54.3766 TIME 1031				
HH		-16.75	-11.26	-7.52
HV	-25.40	-22.57	-17.45	-10.55

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMAO (dB)
SDSU FOOTBALL FIELD

DATE 3/14/79

FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6

ANGLE = 0 DEGREES RANGE 19.7767 TIME 1038

HH	7.74	3.62	6.81	5.73
HV	1.00	-2.31	-1.11	-4.99

ANGLE = 20 DEGREES RANGE 21.3062 TIME 1052

HH	-0.07	-1.96	-0.02	0.25
HV	-4.63	-7.87	-6.06	-4.80

ANGLE = 50 DEGREES RANGE 30.3181 TIME 1103

HH	-13.64	-10.34	-5.85	-1.74
HV	-20.71	-15.99	-11.56	-4.83

ANGLE = 70 DEGREES RANGE 52.9393 TIME 1110

HH		-17.82	-11.34	-8.29
HV	-25.48	-22.44	-21.10	-12.16

ANGLE = 0 DEGREES RANGE 19.7512 TIME 1119

HH	7.70	3.36	4.17	4.81
HV	1.11	-4.03	-1.88	-4.44

ANGLE = 20 DEGREES RANGE 21.1024 TIME 1132

HH	0.52	-1.91	-0.60	-1.19
HV	-2.36	-8.85	-6.83	-3.85

ANGLE = 50 DEGREES RANGE 29.4793 TIME 1140

HH	-13.29	-11.47	-6.39	-2.33
HV	-19.70	-17.96	-11.47	-5.82

ANGLE = 70 DEGREES RANGE 53.3073 TIME 1147

HH		-15.72	-10.60	-6.48
HV	-24.42	-22.26	-17.07	-11.63

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMAO (dB)
SDSU FOOTBALL FIELD

DATE 3/14/79

FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6
ANGLE = 0 DEGREES	RANGE 19.493[illegible]	TIME 1200		
HH	8.17	2.59	7.18	5.89
HV	2.08	-4.96	-1.25	-3.32
ANGLE = 20 DEGREES	RANGE 21.2444	TIME 1210		
HH	1.05	-0.37	1.69	-0.93
HV	-2.87	-6.41	-6.50	-3.74
ANGLE = 50 DEGREES	RANGE 30.7350	TIME 1219		
HH	-14.20	-10.09	-5.89	-1.93
HV	-19.35	-15.52	-12.07	-4.73
ANGLE = 70 DEGREES	RANGE 51.0547	TIME 1225		
HH		-17.48	-11.34	-9.50
HV	-25.20	-22.92	-17.84	-12.48
ANGLE = 0 DEGREES	RANGE 19.6666	TIME 1233		
HH	6.59	2.85	6.46	4.90
HV	-0.08	-4.00	-0.59	-4.25
ANGLE = 20 DEGREES	RANGE 21.4114	TIME 1242		
HH	0.42	-0.80	-0.22	-0.64
HV	-2.60	-7.33	-5.64	-3.37
ANGLE = 50 DEGREES	RANGE 30.2842	TIME 1250		
HH	-14.76	-12.36	-6.30	-1.03
HV	-20.68	-16.28	-11.78	-4.18
ANGLE = 70 DEGREES	RANGE 52.6966	TIME 1256		
HH		-15.39	-10.73	-7.04
HV	-25.32	-22.55	-16.67	-11.38

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMAO (dB)
SDSU FOOTBALL FIELD

DATE 3/14/79

FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6
ANGLE = 0 DEGREES RANGE 20.1221 TIME 1305				
HH	8.92	6.55	8.68	5.61
HV	2.10	-2.42	-0.44	-4.91
ANGLE = 20 DEGREES RANGE 22.2277 TIME 1318				
HH	-0.06	-0.34	-1.36	-1.49
HV	-4.46	-6.27	-7.15	-4.61
ANGLE = 50 DEGREES RANGE 30.6683 TIME 1327				
HH	-15.07	-11.12	-7.05	-1.42
HV	-20.97	-16.90	-12.79	-5.77
ANGLE = 70 DEGREES RANGE 50.8280 TIME 1332				
HH		-17.02	-10.73	-8.96
HV	-24.95	-22.47	-17.34	-12.00
ANGLE = 0 DEGREES RANGE 19.7353 TIME 1340				
HH	8.96	3.15	7.21	6.54
HV	2.20	-4.15	-1.25	-5.31
ANGLE = 20 DEGREES RANGE 22.3040 TIME 1350				
HH	0.83	1.16	-0.53	-1.03
HV	-4.75	-5.05	-7.36	-5.10
ANGLE = 50 DEGREES RANGE 30.5356 TIME 1403				
HH	-14.54	-10.78	-5.81	-1.36
HV	-20.19	-16.51	-12.74	-4.78
ANGLE = 70 DEGREES RANGE 51.9810 TIME 1409				
HH		-16.06	-10.46	-7.50
HV	-24.99	-22.52	-17.05	

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMAO (dB)
SDSU FOOTBALL FIELD

DATE 3/14/79

FREQUENCY (GHZ)

ANGLE = 0 DEGREES   RANGE 20.0314   TIME 1415

	8.6	13.0	17.0	35.6
HH		6.70	7.82	5.35
HV	1.51	-1.37	0.35	-4.19

ANGLE = 20 DEGREES   RANGE 21.6604   TIME 1423

	8.6	13.0	17.0	35.6
HH	0.61	-0.45	0.96	-1.43
HV	-3.41	-5.55	-5.42	-4.94

ANGLE = 50 DEGREES   RANGE 29.2943   TIME 1435

	8.6	13.0	17.0	35.6
HH	-14.63	-13.63	-6.88	-2.52
HV	-20.70	-18.40	-12.83	-5.43

ANGLE = 70 DEGREES   RANGE 53.4311   TIME 1440

	8.6	13.0	17.0	35.6
HH		-17.22	-11.61	-6.70
HV	-25.21	-22.84	-16.79	-12.20

ANGLE = 0 DEGREES   RANGE 19.4882   TIME 1448

	8.6	13.0	17.0	35.6
HH	8.03	2.95	6.43	5.88
HV	1.19	-4.17	0.06	-5.77

ANGLE = 20 DEGREES   RANGE 21.9102   TIME 1459

	8.6	13.0	17.0	35.6
HH	0.73	0.42	-0.28	-0.60
HV	-3.57	-5.37	-5.63	-4.55

ANGLE = 50 DEGREES   RANGE 29.4689   TIME 1505

	8.6	13.0	17.0	35.6
HH	-14.63	-11.98	-6.72	-1.68
HV	-20.99	-17.22	-11.59	-4.00

ANGLE = 70 DEGREES   RANGE 52.6362   TIME 1510

	8.6	13.0	17.0	35.6
HH		-16.16	-10.34	-7.60
HV	-25.03	-21.89	-17.22	-11.51

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMA0 (dB)
SDSU FOOTBALL FIELD

DATE 3/16/79

FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6
ANGLE = 0 DEGREES RANGE 20.6126 TIME 844				
HH	13.56	10.99	9.29	5.16
HV	4.38	2.25	1.01	-3.24
ANGLE = 20 DEGREES RANGE 21.7363 TIME 859				
HH	-0.61	-3.84	-2.39	-0.61
HV	-5.94	-9.64	-8.73	-2.97
ANGLE = 50 DEGREES RANGE 31.9948 TIME 907				
HH	-12.53	-12.45	-6.94	-2.33
HV	-19.93	-17.90	-12.81	-6.54
ANGLE = 70 DEGREES RANGE 60.1553 TIME 913				
HH			-16.01	-14.28
HV	-24.03	-24.05	-20.17	-18.38
ANGLE = 0 DEGREES RANGE 20.2731 TIME 925				
HH	12.92	8.66	9.16	6.71
HV	4.85	1.52	1.63	-6.05
ANGLE = 20 DEGREES RANGE 21.9254 TIME 941				
HH	-2.20	-3.38	-3.55	-4.84
HV	-7.40	-9.76	-22.49	-9.65
ANGLE = 50 DEGREES RANGE 31.3015 TIME 951				
HH	-15.63	-17.12	-13.85	-12.43
HV	-23.08	-21.26	-18.56	-17.66
ANGLE = 70 DEGREES RANGE 59.6977 TIME 956				
HH			-23.13	-24.94
HV	-26.45	-28.57	-27.02	-31.63

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMA0 (dB)
SDSU FOOTBALL FIELD

DATE 3/16/79

FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6

ANGLE = 0 DEGREES RANGE 19.9931 TIME 1005

HH	10.95	6.64	6.18	5.36
HV	2.82	-1.57	-1.76	-14.14

ANGLE = 20 DEGREES RANGE 22.5576 TIME 1023

HH	-5.22	-5.39	-8.49	-9.95
HV	-10.98	-14.08	-15.35	-19.44

ANGLE = 50 DEGREES RANGE 31.8396 TIME 1031

HH	-17.22	-19.56	-17.95	-14.09
HV	-24.46	-24.53	-23.82	-24.52

ANGLE = 70 DEGREES RANGE 64.0300 TIME 1036

HH			-25.08	-23.22
HV	-26.22	-30.44	-30.68	-31.72

ANGLE = 0 DEGREES RANGE 20.1668 TIME 1047

HH	11.01	7.77	8.40	4.29
HV	1.88	-0.37	-0.10	-16.06

ANGLE = 20 DEGREES RANGE 22.9270 TIME 1102

HH	-8.70	-9.41	-10.81	-11.98
HV	-14.83	-14.50	-16.84	-21.09

ANGLE = 50 DEGREES RANGE 31.9349 TIME 1111

HH	-18.33	-21.58	-18.33	-14.23
HV	-25.40	-26.28	-25.52	-22.90

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMAO (dB)
SDSU FOOTBALL FIELD

DATE 3/16/79

FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6
ANGLE = 0 DEGREES	RANGE 19.7966	TIME 1124		
HH	11.30	6.60	7.78	4.63
HV	0.69	0.76	0.03	-15.49
ANGLE = 20 DEGREES	RANGE 21.8384	TIME 1138		
HH	-8.86	-9.89	-11.73	-11.68
HV	-14.42	-16.86	-18.41	-21.00
ANGLE = 50 DEGREES	RANGE 31.6506	TIME 1149		
HH		-22.40	-19.65	-14.03
HV	-25.78	-26.03	-25.37	-22.95
ANGLE = 70 DEGREES	RANGE 58.7189	TIME 1155		
HH			-25.85	-23.72
HV	-27.00	-31.43	-31.33	-32.57
ANGLE = 0 DEGREES	RANGE 20.0354	TIME 1210		
HH	11.67	7.64	8.12	5.91
HV	-0.07	-0.16	-0.01	-15.95
ANGLE = 20 DEGREES	RANGE 22.1902	TIME 1226		
HH	-7.18	-10.22	-12.00	-9.81
HV	-16.44	-14.05	-18.71	-18.86
ANGLE = 50 DEGREES	RANGE 32.1982	TIME 1234		
HH		-20.91	-18.23	-14.12
HV	-25.89	-26.33	-25.71	-22.25
ANGLE = 70 DEGREES	RANGE 62.8287	TIME 1241		
HH			-25.81	-22.84
HV	-26.74	-31.68	-30.37	-31.35

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMAO (dB)
SDSU FOOTBALL FIELD

DATE 3/16/79

FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6
ANGLE = 0 DEGREES RANGE 20.3019 TIME 1248				
HH	11.44	10.12	10.20	4.92
HV	1.75	1.59	0.67	-15.71
ANGLE = 20 DEGREES RANGE 22.2361 TIME 1305				
HH	-9.85	-10.53	-11.31	-10.16
HV	-16.79	-17.65	-18.09	-20.14
ANGLE = 50 DEGREES RANGE 32.4809 TIME 1313				
HH		-22.36	-18.98	-11.95
HV	-26.57	-25.05	-25.01	-21.79
ANGLE = 70 DEGREES RANGE 60.3155 TIME 1318				
HH			-24.41	-21.95
HV	-27.12	-31.78	-29.54	-30.72
ANGLE = 0 DEGREES RANGE 20.0534 TIME 1324				
HH	10.84	6.56	8.77	4.54
HV	0.82	-0.52	-0.10	-16.60
ANGLE = 20 DEGREES RANGE 22.3073 TIME 1340				
HH	-10.42	-10.53	-11.17	-10.83
HV	-16.78	-17.37	-18.35	-21.15
ANGLE = 50 DEGREES RANGE 32.2848 TIME 1348				
HH		-21.22	-19.13	-12.51
HV	-26.43	-26.45	-26.01	-22.74
ANGLE = 70 DEGREES RANGE 66.2875 TIME 1354				
HH			-25.44	-21.65
HV	-26.46	-30.86	-30.16	-29.76

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMA0 (dB)
SDSU FOOTBALL FIELD

DATE 3/16/79

FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6
ANGLE = 0 DEGREES RANGE 20.2299 TIME 1401				
HH	11.03	6.46	6.85	4.11
HV	-0.71	0.19	-1.37	-15.98
ANGLE = 20 DEGREES RANGE 22.2647 TIME 1413				
HH	-10.89	-10.52	-10.72	-11.08
HV	-16.95	-16.41	-17.70	-19.95
ANGLE = 50 DEGREES RANGE 32.8543 TIME 1423				
HH		-21.71	-19.23	-12.90
HV	-27.31	-26.39	-24.92	-22.14
ANGLE = 70 DEGREES RANGE 62.8287 TIME 1428				
HH			-24.73	-21.95
HV	-26.98	-31.08	-29.97	-31.20
ANGLE = 0 DEGREES RANGE 20.3122 TIME 1439				
HH	9.57	10.08	10.01	6.50
HV	0.95	1.15	-0.12	-14.28
ANGLE = 20 DEGREES RANGE 23.1562 TIME 1453				
HH	-15.09	-10.14	-13.43	-11.87
HV	-21.66	-17.05	-18.34	-21.38
ANGLE = 50 DEGREES RANGE 32.0548 TIME 1505				
HH		-21.45	-18.81	-13.30
HV	-26.26	-26.29	-24.98	-21.83
ANGLE = 70 DEGREES RANGE 61.5072 TIME 1511				
HH			-24.13	-21.19
HV	-26.83	-30.46	-29.34	-30.50

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMAO (dB)
SDSU FOOTBALL FIELD

DATE 3/16/79

FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6

ANGLE = 0 DEGREES RANGE 20.2833 TIME 1518

HH	10.55	10.41	10.13	5.13
HV	1.95	1.19	1.60	-15.14

ANGLE = 20 DEGREES RANGE 23.1178 TIME 1532

HH	-16.56	-12.76	-14.02	-12.91
HV	-22.18	-15.91	-18.87	-22.54

ANGLE = 50 DEGREES RANGE 31.7922 TIME 1541

HH		-23.15	-18.60	-14.09
HV	-26.18	-26.44	-24.30	-22.80

ANGLE = 70 DEGREES RANGE 63.2528 TIME 1546

HH			-24.61	-20.89
HV	-26.85	-31.02	-29.71	-30.60

ANGLE = 0 DEGREES RANGE 20.6054 TIME 1553

HH	10.14	8.99	9.16	5.55
HV	1.20	1.72	0.79	-15.53

ANGLE = 20 DEGREES RANGE 22.1486 TIME 1604

HH	-9.79	-10.26	-11.79	-10.99
HV	-16.56	-16.21	-16.91	-19.60

ANGLE = 50 DEGREES RANGE 32.4809 TIME 1613

HH		-21.94	-19.18	-13.34
HV	-26.79	-25.86	-24.40	-21.76

ANGLE = 70 DEGREES RANGE 61.9145 TIME 1620

HH			-23.95	-20.64
HV	-27.16	-31.02	-29.86	-29.72

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMA0 (dB)
SDSU FOOTBALL FIELD

DATE3/16/79

FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6

ANGLE = 0 DEGREES RANGE 20.4594 TIME 1626

HH	9.02	10.10	8.89	5.94
HV	1.18	2.09	1.46	-15.22

ANGLE = 20 DEGREES RANGE 22.4085 TIME 1639

HH	-11.22	-11.13	-12.71	-10.89
HV	-18.03	-15.48	-18.32	-20.34

ANGLE = 50 DEGREES RANGE 32.5055 TIME 1648

HH		-21.70	-19.67	-12.59
HV	-26.52	-25.79	-24.42	-23.33

ANGLE = 70 DEGREES RANGE 63.6823 TIME 1654

HH			-24.37	-21.85
HV	-26.73	-30.60	-29.64	-29.97

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMAO (dB)
STAUROLITE SNOWDRIFT

DATE 3/13/79

FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6

ANGLE = 40 DEGREES RANGE 14.6307 TIME 825

HH	-10.49	-10.77	-10.79	-8.16
HV	-14.47	-14.97	-12.95	-9.58

ANGLE = 50 DEGREES RANGE 18.4029 TIME 837

HH	-13.51	-13.09	-12.65	-9.06
HV	-17.26	-17.13	-15.92	-14.30

ANGLE = 75 DEGREES RANGE 41.7222 TIME 842

HH	-21.20	-21.32	-16.29	-14.51
HV	-27.24	-26.79	-21.97	-19.58

ANGLE = 40 DEGREES RANGE 14.6709 TIME 849

HH	-10.38	-9.86	-9.67	-7.92
HV	-14.13	-13.94	-13.36	-10.79

ANGLE = 50 DEGREES RANGE 17.0661 TIME 854

HH	-11.87	-12.06	-10.83	-7.88
HV	-17.64	-18.63	-14.92	-13.06

ANGLE = 75 DEGREES RANGE 42.1556 TIME 901

HH	-19.82	-20.03	-16.12	-14.13
HV	-26.33	-25.35	-21.21	-18.73

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMAO (dB)
STAUROLITE SNOWDRIFT

DATE 3/13/79

FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6

ANGLE = 40 DEGREES RANGE 14.3724 TIME 907

HH	-9.61	-10.02	-8.89	-5.92
HV	-13.64	-15.15	-14.13	-10.12

ANGLE = 50 DEGREES RANGE 16.8611 TIME 916

HH	-11.46	-11.26	-10.39	-5.62
HV	-16.08	-17.26	-15.89	-10.79

ANGLE = 75 DEGREES RANGE 42.6789 TIME 922

HH	-20.31	-21.10	-17.50	-14.24
HV	-27.33	-26.57	-23.00	-17.92

ANGLE = 40 DEGREES RANGE 14.5113 TIME 927

HH	-10.53	-10.90	-9.09	-7.94
HV	-14.27	-14.61	-13.85	-11.62

ANGLE = 50 DEGREES RANGE 16.9833 TIME 934

HH	-11.35	-13.21	-10.39	-6.90
HV	-15.34	-17.56	-15.15	-11.36

ANGLE = 75 DEGREES RANGE 43.1312 TIME 942

HH	-20.42	-19.57	-15.96	-12.36
HV	-27.33	-25.37	-22.25	-16.99

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMAO (dB)
STAUROLITE SNOWDRIFT

DATE 3/13/79

FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6
ANGLE = 40 DEGREES RANGE 14.4325 TIME 959				
HH	-9.13	-8.85	-8.80	-7.92
HV	-13.68	-14.70	-13.97	-10.36
ANGLE = 50 DEGREES RANGE 17.0423 TIME 1005				
HH	-11.26	-10.54	-9.67	-6.01
HV	-16.09	-16.03	-15.44	-9.77
ANGLE = 75 DEGREES RANGE 41.8004 TIME 1010				
HH	-19.55	-18.95	-15.21	-12.53
HV	-26.38	-24.74	-21.52	-18.08
ANGLE = 40 DEGREES RANGE 14.3455 TIME 1030				
HH	-10.61	-11.42	-9.34	-7.32
HV	-13.18	-14.68	-13.68	-11.52
ANGLE = 50 DEGREES RANGE 17.0661 TIME 1036				
HH	-11.03	-9.63	-8.36	-7.54
HV	-15.08	-16.72	-16.38	-12.37
ANGLE = 75 DEGREES RANGE 41.4891 TIME 1044				
HH	-19.72	-19.53	-14.83	-13.12
HV	-26.26	-24.83	-21.64	-17.60

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMAO (dB)
STAUROLITE SNOWDRIFT

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FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6
ANGLE = 40 DEGREES RANGE 14.2475 TIME 1100				
HH	-10.62	-9.32	-9.02	-7.01
HV	-14.35	-14.27	-13.07	-11.19
ANGLE = 50 DEGREES RANGE 16.9002 TIME 1108				
HH	-11.06	-10.82	-9.96	-7.09
HV	-15.31	-16.47	-15.48	-12.56
ANGLE = 75 DEGREES RANGE 41.3352 TIME 1115				
HH	-19.40	-18.78	-14.74	-13.89
HV	-26.12	-24.81	-21.92	-17.36
ANGLE = 40 DEGREES RANGE 14.1506 TIME 1158				
HH	-9.60	-9.46	-7.03	-6.04
HV	-14.10	-14.81	-13.10	-10.76
ANGLE = 50 DEGREES RANGE 17.4971 TIME 1203				
HH	-10.93	-10.55	-9.71	-8.50
HV	-15.25	-16.24	-14.84	-11.40
ANGLE = 75 DEGREES RANGE 39.2506 TIME 1208				
HH	-20.08	-20.20	-15.24	-13.72
HV	-25.73	-25.12	-21.80	-18.86

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMAO (dB)
STAUROLITE SNOWDRIFT

DATE 3/13/79

FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6
ANGLE = 40 DEGREES RANGE 14.3156 TIME 1233				
HH	-10.37	-9.01	-9.10	-6.71
HV	-13.75	-15.17	-14.53	-10.87
ANGLE = 50 DEGREES RANGE 16.2594 TIME 1239				
HH	-10.51	-12.05	-8.21	-7.21
HV	-14.99	-18.15	-13.99	-10.53
ANGLE = 75 DEGREES RANGE 42.3154 TIME 1244				
HH	-18.95	-18.22	-15.46	-13.51
HV	-26.48	-25.11	-21.63	-18.18
ANGLE = 40 DEGREES RANGE 14.4475 TIME 1302				
HH	-11.46	-9.97	-9.95	-7.63
HV	-13.99	-13.69	-13.56	-10.72
ANGLE = 50 DEGREES RANGE 17.3815 TIME 1307				
HH	-10.93	-9.93	-8.47	-7.37
HV	-15.87	-16.27	-14.40	-12.09
ANGLE = 75 DEGREES RANGE 41.4120 TIME 1313				
HH	-20.01	-18.41	-14.08	-13.53
HV	-26.07	-24.64	-21.14	-17.15

BROOKINGS, SOUTH DAKOTA 1979
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STAUROLITE SNOWDRIFT

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FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6
ANGLE = 40 DEGREES RANGE 14.4145 TIME 1328				
HH	-10.76	-9.48	-9.63	-7.61
HV	-13.32	-13.88	-13.39	-11.08
ANGLE = 50 DEGREES RANGE 17.1381 TIME 1334				
HH	-10.45	-10.55	-9.00	-8.40
HV	-14.69	-16.43	-15.08	-11.59
ANGLE = 75 DEGREES RANGE 41.4506 TIME 1339				
HH	-18.60	-18.59	-14.53	-12.58
HV	-25.79	-23.67	-20.78	-16.37
ANGLE = 40 DEGREES RANGE 16.1100 TIME 1405				
HH	-14.27	-12.84	-12.39	-16.56
HV	-16.37	-14.27	-15.52	-19.91
ANGLE = 50 DEGREES RANGE 17.1581 TIME 1411				
HH	-11.92	-9.20	-9.70	-7.26
HV	-14.93	-15.81	-15.24	-11.68
ANGLE = 75 DEGREES RANGE 41.7293 TIME 1417				
HH	-19.43	-18.57	-14.65	-12.81
HV	-25.76	-23.91	-20.89	-16.10

BROOKINGS, SOUTH DAKOTA 1979
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DATE 3/13/79

FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6
ANGLE = 40 DEGREES RANGE 14.1711 TIME 1432				
HH	-9.11	-9.96	-7.80	-7.95
HV	-13.17	-14.85	-12.37	-10.68
ANGLE = 50 DEGREES RANGE 16.3925 TIME 1439				
HH	-10.98	-10.58	-9.60	-5.71
HV	-15.50	-16.89	-15.19	-10.93
ANGLE = 75 DEGREES RANGE 40.6180 TIME 1445				
HH	-16.90	-18.71	-14.20	-12.62
HV	-25.02	-23.99	-20.34	-17.12
ANGLE = 40 DEGREES RANGE 14.2564 TIME 1502				
HH	-9.03	-8.74	-6.99	-6.82
HV	-13.78	-15.18	-11.97	-11.06
ANGLE = 50 DEGREES RANGE 16.6833 TIME 1508				
HH	-10.38	-10.70	-7.73	-7.11
HV	-15.08	-15.97	-14.46	-10.94
ANGLE = 75 DEGREES RANGE 39.8875 TIME 1515				
HH	-17.42	-18.80	-14.45	-12.92
HV	-24.80	-23.28	-20.42	-17.06

BROOKINGS, SOUTH DAKOTA 1979
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DATE 3/15/79

FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6
ANGLE = 40 DEGREES RANGE 17.3939 TIME 912				
HH	-6.73	-7.24	-5.21	-6.61
HV	-13.43	-13.98	-10.16	-10.39
ANGLE = 50 DEGREES RANGE 19.1929 TIME 918				
HH	-11.26	-13.72	-7.91	-6.39
HV	-15.55	-18.84	-13.56	-9.51
ANGLE = 75 DEGREES RANGE 46.6126 TIME 926				
HH	-14.79	-16.79	-11.23	-11.54
HV	-21.59	-21.41	-15.40	-15.56
ANGLE = 40 DEGREES RANGE 16.9538 TIME 934				
HH	-6.36	-7.05	-5.42	-5.58
HV	-12.17	-14.48	-10.57	-9.88
ANGLE = 50 DEGREES RANGE 19.5658 TIME 942				
HH	-11.75	-13.60	-8.76	-7.23
HV	-16.70	-17.93	-13.09	-8.94
ANGLE = 75 DEGREES RANGE 39.2506 TIME 947				
HH	-14.45	-13.89	-11.46	-10.13
HV	-21.44	-20.29	-16.49	-13.82

BROOKINGS, SOUTH DAKOTA 1979
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DATE 3/15/79

FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6
ANGLE = 40 DEGREES RANGE 16.4218 TIME 955				
HH	-7.34	-10.48	-5.99	-5.42
HV	-13.57	-16.23	-11.10	-8.71
ANGLE = 50 DEGREES RANGE 19.7429 TIME 1003				
HH	-10.21	-10.04	-6.48	-5.39
HV	-15.66	-16.47	-11.45	-8.26
ANGLE = 75 DEGREES RANGE 46.6606 TIME 1008				
HH	-14.40	-16.46	-11.46	-11.81
HV	-21.49	-21.13	-16.49	-16.02
ANGLE = 40 DEGREES RANGE 16.3105 TIME 1014				
HH	-7.95	-10.64	-5.63	-5.50
HV	-13.32	-16.37	-10.69	-8.94
ANGLE = 50 DEGREES RANGE 20.2113 TIME 1021				
HH	-10.54	-9.40	-6.08	-5.95
HV	-16.07	-15.83	-12.10	-10.23
ANGLE = 75 DEGREES RANGE 47.5912 TIME 1027				
HH	-14.41	-15.62	-10.88	-11.02
HV	-21.98	-20.68	-14.17	-15.14

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMAO (dB)
STAUROLITE SNOWDRIFT

DATE 3/15/79

FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6
ANGLE = 40 DEGREES RANGE 17.0204 TIME 1032				
HH	-6.59	-8.36	-6.14	-5.74
HV	-12.56	-14.09	-10.92	-9.38
ANGLE = 50 DEGREES RANGE 20.3448 TIME 1040				
HH	-11.19	-9.09	-6.51	-6.81
HV	-15.75	-16.89	-13.70	-10.89
ANGLE = 75 DEGREES RANGE 46.9994 TIME 1049				
HH	-15.31	-15.86	-11.04	-10.55
HV	-22.19	-20.51	-15.26	-14.96
ANGLE = 40 DEGREES RANGE 16.4373 TIME 1055				
HH	-6.88	-8.63	-5.33	-5.45
HV	-12.62	-16.18	-11.40	-8.69
ANGLE = 50 DEGREES RANGE 20.1214 TIME 1100				
HH	-10.30	-11.59	-8.51	-7.45
HV	-14.54	-15.70	-13.02	-9.30
ANGLE = 75 DEGREES RANGE 25.8413 TIME 1106				
HH	-14.76	-16.27	-13.71	-11.01
HV	-20.46	-21.97	-18.91	-15.47

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMAO (dB)
STAUROLITE SNOWDRIFT

DATE 3/15/79

FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6
ANGLE = 40 DEGREES RANGE 16.7564 TIME 1114				
HH	-7.47	-8.64	-7.06	-7.12
HV	-12.14	-16.14	-12.10	-8.91
ANGLE = 50 DEGREES RANGE 20.0164 TIME 1119				
HH	-10.50	-10.42	-7.03	-5.49
HV	-16.33	-16.57	-13.59	-10.38
ANGLE = 75 DEGREES RANGE 45.8564 TIME 1125				
HH	-14.84	-16.16	-11.65	-12.50
HV	-21.53	-21.24	-17.14	-14.93
ANGLE = 40 DEGREES RANGE 16.8315 TIME 1131				
HH	-6.93	-8.64	-6.90	-5.62
HV	-12.00	-14.71	-11.71	-8.79
ANGLE = 50 DEGREES RANGE 20.0668 TIME 1138				
HH	-10.55	-10.64	-7.17	-5.96
HV	-14.79	-16.59	-13.78	-8.97
ANGLE = 75 DEGREES RANGE 46.0903 TIME 1146				
HH	-14.73	-16.87	-11.85	-11.93
HV	-22.04	-21.71	-16.49	-14.99

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMAO (dB)
STAUROLITE SNOWDRIFT

DATE 3/15/79

FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6

ANGLE = 40 DEGREES RANGE 16.5727 TIME 1152

HH	-6.43	-9.52	-6.31	-6.68
HV	-11.96	-15.00	-11.79	-8.57

ANGLE = 50 DEGREES RANGE 19.8351 TIME 1157

HH	-10.81	-12.84	-8.31	-5.41
HV	-14.87	-16.92	-13.83	-10.37

ANGLE = 75 DEGREES RANGE 52.3167 TIME 1203

HH	-15.00	-15.81	-11.00	-11.18
HV	-21.61	-19.31	-16.12	-13.82

ANGLE = 40 DEGREES RANGE 16.8416 TIME 1209

HH	-7.29	-8.17	-7.34	-6.28
HV	-13.11	-16.13	-12.93	-9.08

ANGLE = 50 DEGREES RANGE 20.2859 TIME 1215

HH	-10.90	-10.23	-8.21	-8.12
HV	-15.35	-15.16	-13.26	-8.66

ANGLE = 75 DEGREES RANGE 47.6911 TIME 1220

HH	-14.73	-15.23	-10.78	-10.26
HV	-21.36	-20.31	-16.12	-14.36

BROOKINGS, SOUTH DAKOTA 1979
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FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6

ANGLE = 40 DEGREES   RANGE 16.7757   TIME 1226

HH	-6.38	-7.45	-5.28	-4.63
HV	-12.27	-13.91	-11.94	-8.23

ANGLE = 50 DEGREES   RANGE 20.2220   TIME 1231

HH	-10.02	-10.97	-7.12	-6.20
HV	-14.44	-15.88	-13.11	-10.14

ANGLE = 75 DEGREES   RANGE 47.5912   TIME 1235

HH	-14.63	-17.45	-12.44	-13.42
HV	-21.25	-21.08	-16.69	-16.20

ANGLE = 40 DEGREES   RANGE 16.6948   TIME 1242

HH	-6.95	-7.92	-5.03	-4.48
HV	-11.93	-14.64	-10.68	-8.58

ANGLE = 50 DEGREES   RANGE 20.0793   TIME 1246

HH	-10.69	-11.33	-7.90	-5.32
HV	-14.85	-15.75	-12.80	-9.19

ANGLE = 75 DEGREES   RANGE 20.0793   TIME 1251

HH	-13.58	-14.44	-10.68	-10.22
HV	-20.36	-19.07	-14.55	-13.06

BROOKINGS, SOUTH DAKOTA 1979
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FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6

ANGLE = 40 DEGREES RANGE 16.6145 TIME 1257

HH	-6.40	-8.64	-5.97	-3.54
HV	-12.17	-15.48	-12.67	-9.27

ANGLE = 50 DEGREES RANGE 19.9176 TIME 1303

HH	-10.96	-10.49	-7.99	-6.90
HV	-14.15	-15.77	-13.63	-8.30

ANGLE = 75 DEGREES RANGE 50.2694 TIME 1308

HH	-14.86	-15.31	-11.00	-9.71
HV	-21.13	-18.97	-16.03	-14.07

ANGLE = 40 DEGREES RANGE 16.9041 TIME 1315

HH	-7.20	-8.11	-5.24	-4.94
HV	-12.13	-15.24	-11.80	-8.88

ANGLE = 50 DEGREES RANGE 19.7226 TIME 1321

HH	-11.05	-11.13	-6.84	-5.86
HV	-15.14	-16.83	-13.03	-8.96

ANGLE = 75 DEGREES RANGE 50.3248 TIME 1326

HH	-15.44	-15.28	-11.21	-9.71
HV	-21.62	-19.27	-15.88	-14.55

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BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMA0 (dB)
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FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6
ANGLE = 40 DEGREES RANGE 16.5918 TIME 1335				
HH	-7.36	-10.49	-6.47	-4.22
HV	-12.29	-16.35	-12.75	8.03
ANGLE = 50 DEGREES RANGE 21.1616 TIME 1339				
HH	-11.19	7.44	-6.76	-6.31
HV	-15.35	-14.70	-13.24	-9.88
ANGLE = 75 DEGREES RANGE 49.5603 TIME 1345				
HH	-14.30	-15.58	-11.40	-10.29
HV	-21.29	-20.23	-15.88	-13.87
ANGLE = 40 DEGREES RANGE 17.5388 TIME 1351				
HH	-7.02	-8.28	-5.25	-6.98
HV	-12.24	-13.68	-12.61	-9.77
ANGLE = 50 DEGREES RANGE 20.9564 TIME 1357				
HH	-10.51	-9.73	-7.18	-6.83
HV	-14.88	-14.24	-12.91	-9.49
ANGLE = 75 DEGREES RANGE 51.2834 TIME 1402				
HH	-15.36	-14.29	-11.64	-10.93
HV	-21.29	-19.09	-15.85	-13.64

BROOKINGS, SOUTH DAKOTA 1979
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FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6
ANGLE = 40 DEGREES RANGE 16.8387 TIME 1408				
HH	-7.06	-9.69	-6.34	-4.55
HV	-13.29	-15.31	-11.65	-8.41
ANGLE = 50 DEGREES RANGE 21.2077 TIME 1416				
HH	-11.42	-9.45	-8.12	-6.99
HV	-15.12	-14.57	-13.12	-10.51
ANGLE = 75 DEGREES RANGE 50.0492 TIME 1422				
HH	-15.03	-15.98	-11.30	-11.39
HV	-20.95	-19.82	-15.42	-15.12
ANGLE = 40 DEGREES RANGE 17.6056 TIME 1427				
HH	-7.46	-6.85	-6.61	-5.83
HV	-11.82	-13.72	-10.60	-9.37
ANGLE = 50 DEGREES RANGE 20.8551 TIME 1432				
HH	-10.32	-8.87	-7.40	-5.79
HV	-15.42	-14.58	-12.33	-9.78
ANGLE = 75 DEGREES RANGE 51.2260 TIME 1438				
HH	-14.98	-15.24	-12.71	-10.48
HV	-22.00	-19.95	-16.23	-13.56

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMAO (dB)
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FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6

ANGLE = 40 DEGREES RANGE 17.5763 TIME 1443

HH	-7.19	-6.15	-5.14	-4.70
HV	-11.59	-12.36	-11.37	-9.64

ANGLE = 50 DEGREES RANGE 21.1962 TIME 1448

HH	-10.96	-8.61	-7.37	-6.26
HV	-15.33	-14.37	-12.62	-10.30

ANGLE = 75 DEGREES RANGE 51.3984 TIME 1453

HH	-14.52	-15.01	-10.65	-11.27
HV	-21.53	-19.77	-16.38	-14.30

ANGLE = 40 DEGREES RANGE 17.5680 TIME 1500

HH	-7.36	-7.01	-6.08	-4.12
HV	-12.28	-12.96	-11.66	-9.73

ANGLE = 50 DEGREES RANGE 20.6054 TIME 1504

HH	-10.11	-10.06	-7.19	-5.60
HV	-15.69	-15.34	-13.38	-8.96

ANGLE = 75 DEGREES RANGE 50.0492 TIME 1510

HH	-14.64	-15.34	-11.43	-10.38
HV	-21.22	-19.50	-15.82	-14.26

BROOKINGS, SOUTH DAKOTA 1979
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FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6
ANGLE = 40 DEGREES RANGE 17.0344 TIME 1516				
HH	-7.20	-7.86	-5.17	-5.92
HV	-11.63	-14.89	-10.58	-9.34
ANGLE = 50 DEGREES RANGE 20.2007 TIME 1521				
HH	-10.27	-10.35	-6.51	-5.08
HV	-15.72	-16.54	-13.43	-9.31
ANGLE = 75 DEGREES RANGE 49.7222 TIME 1526				
HH	-14.51	-15.55	-10.96	-10.56
HV	-21.58	-20.52	-15.28	-14.72
ANGLE = 40 DEGREES RANGE 17.7748 TIME 1531				
HH	-6.94	-7.33	-7.26	-6.12
HV	-11.78	-11.56	-11.03	-8.98
ANGLE = 50 DEGREES RANGE 21.1789 TIME 1536				
HH	-9.75	-8.46	-6.44	-6.22
HV	-15.04	-13.01	-12.32	-9.62
ANGLE = 75 DEGREES RANGE 51.6300 TIME 1541				
HH	-14.34	-15.01	-10.77	-10.70
HV	-21.64	-19.69	-15.95	-15.16

BROOKINGS, SOUTH DAKOTA 1979
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FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6
ANGLE = 40 DEGREES	RANGE 17.0677		TIME 1549	
HH	-6.62	-9.06	-5.20	-5.68
HV	-12.23	-13.98	-10.58	-9.44
ANGLE = 50 DEGREES	RANGE 20.1478		TIME 1556	
HH	-11.11	-10.56	-6.79	-5.13
HV	-15.16	-16.50	-13.46	-8.96
ANGLE = 75 DEGREES	RANGE 50.3802		TIME 1600	
HH	-14.58	-15.64	-11.19	-10.69
HV	-21.77	-19.65	-15.84	-14.07
ANGLE = 40 DEGREES	RANGE 17.0542		TIME 1750	
HH	-6.77	-8.97	-4.29	-4.86
HV	-11.40	-14.36	-11.48	-8.46
ANGLE = 50 DEGREES	RANGE 20.0321		TIME 1756	
HH	-10.55	-11.04	-7.88	-6.18
HV	-16.14	-15.78	-13.58	-9.56
ANGLE = 75 DEGREES	RANGE 52.1581		TIME 1803	
HH	-14.99	-15.28	-11.06	-10.87
HV	-21.56	-19.33	-16.43	-14.48

BROOKINGS, SOUTH DAKOTA 1979
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FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6
ANGLE = 40 DEGREES	RANGE 17.0105	TIME 2029		
HH	-6.63	-7.94	-5.76	-4.63
HV	-11.95	-13.50	-10.48	-7.89
ANGLE = 50 DEGREES	RANGE 19.9073	TIME 2034		
HH	-10.09	-10.22	-7.15	-5.90
HV	-15.95	-17.25	-13.31	-10.16
ANGLE = 75 DEGREES	RANGE 49.1862	TIME 2039		
HH	-15.13	-16.09	-11.39	-10.80
HV	-21.59	-19.88	-16.65	-14.47
ANGLE = 40 DEGREES	RANGE 16.1463	TIME 2133		
HH	-10.34	-14.07	-10.14	-6.77
HV	-14.32	-18.98	-14.77	-12.58
ANGLE = 50 DEGREES	RANGE 21.1732	TIME 2139		
HH	-10.46	-8.79	-7.09	-6.35
HV	-14.51	-13.50	-12.06	-9.08
ANGLE = 75 DEGREES	RANGE 48.1970	TIME 2144		
HH	-14.95	-15.86	-11.42	-10.42
HV	-21.12	-19.84	-16.74	-15.14

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMAO (dB)
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FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6

ANGLE = 40 DEGREES RANGE 16.6245 TIME 746

HH	-13.73	-19.02	-16.93	-16.30
HV	-22.22	-24.69	-22.87	-27.22

ANGLE = 50 DEGREES RANGE 21.4702 TIME 755

HH	-18.77	-20.70	-19.66	-18.76
HV	-24.79	-25.01	-24.97	-28.54

ANGLE = 75 DEGREES RANGE 53.6802 TIME 802

HH		-27.11	-23.66	-24.20
HV	-27.48	-30.43	-28.40	-32.50

ANGLE = 40 DEGREES RANGE 17.0383 TIME 810

HH	-14.50	-17.76	-16.88	-16.36
HV	-20.92	-22.44	-23.30	-26.93

ANGLE = 50 DEGREES RANGE 20.3073 TIME 817

HH	-16.91	-20.96	-21.24	-18.89
HV	-23.90	-25.29	-25.78	-28.35

ANGLE = 75 DEGREES RANGE 61.4264 TIME 823

HH		-23.82	-21.97	-21.25
HV	-27.27	-28.55	-27.68	-29.73

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMAO (dB)
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FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6
ANGLE = 40 DEGREES RANGE 16.3702 TIME 830				
HH	-14.33	-21.14	-20.09	-17.01
HV	-22.23	-25.66	-25.93	-26.64
ANGLE = 50 DEGREES RANGE 20.4853 TIME 836				
HH	-17.81	-21.33	-21.76	-19.64
HV	-25.24	-26.14	-25.87	-27.57
ANGLE = 75 DEGREES RANGE 59.3932 TIME 842				
HH		-25.27	-23.04	-22.70
HV	-27.31	-29.94	-29.54	-30.14
ANGLE = 40 DEGREES RANGE 18.2993 TIME 849				
HH	-17.63	-18.20	-19.24	-17.71
HV	-23.89	-23.38	-25.55	-29.65
ANGLE = 50 DEGREES RANGE 20.3663 TIME 854				
HH	-17.12	-21.93	-21.70	-18.31
HV	-24.22	-26.16	-26.27	-27.25
ANGLE = 75 DEGREES RANGE 60.3936 TIME 900				
HH		-24.54	-22.43	-21.34
HV	-27.02	-29.33	-28.44	-29.27

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BROOKINGS, SOUTH DAKOTA 1979
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FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6

ANGLE = 40 DEGREES RANGE 17.1260 TIME 905

HH	-15.76	-20.10	-18.17	-17.51
HV	-22.43	-23.50	-25.49	-26.88

ANGLE = 50 DEGREES RANGE 19.9956 TIME 911

HH	-17.54	-22.20	-21.35	-17.80
HV	-23.79	-26.56	-26.85	-28.31

ANGLE = 75 DEGREES RANGE 58.4973 TIME 917

HH		-24.68	-22.21	-2[illegible].73
HV	-27.14	-28.86	-28.30	-28.23

ANGLE = 40 DEGREES RANGE 17.0677 TIME 923

HH	-15.27	-19.65	-18.38	-17.18
HV	-22.67	-24.71	-25.11	-27.03

ANGLE = 50 DEGREES RANGE 19.8763 TIME 931

HH	-18.04	-22.55	-21.79	-17.78
HV	-23.98	-26.79	-26.85	-28.38

ANGLE = 75 DEGREES RANGE 57.6984 TIME 936

HH		-25.28	-21.69	-20.90
HV	-27.58	-30.23	-28.37	-28.88

BROOKINGS, SOUTH DAKOTA 1979
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FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6

ANGLE = 40 DEGREES RANGE 16.9632 TIME 942

HH	-15.47	-19.06	-18.04	-17.49
HV	-23.26	-23.50	-23.69	-25.91

ANGLE = 50 DEGREES RANGE 20.1458 TIME 948

HH	-18.46	-21.79	-21.55	-20.27
HV	-25.01	-26.49	-25.56	-27.71

ANGLE = 75 DEGREES RANGE 57.6267 TIME 956

HH		-24.97	-23.27	-22.21
HV	-27.44	-29.35	-28.40	-28.89

ANGLE = 40 DEGREES RANGE 17.2145 TIME 1005

HH	-16.38	-19.53	-19.00	-16.43
HV	-23.05	-24.28	-24.83	-27.81

ANGLE = 50 DEGREES RANGE 20.4527 TIME 1011

HH	-19.22	-22.17	-20.35	-17.89
HV	-24.07	-26.04	-26.28	-29.10

ANGLE = 75 DEGREES RANGE 51.8049 TIME 1017

HH		-26.04	-25.07	-25.24
HV	-28.20	-31.79	-30.31	-32.68

BROOKINGS, SOUTH DAKOTA 1979
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FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6
ANGLE = 40 DEGREES RANGE 17.3759 TIME 1031				
HH	-16.72	-18.79	-17.27	-16.49
HV	-23.24	-24.19	-24.66	-27.02
ANGLE = 50 DEGREES RANGE 20.3394 TIME 1039				
HH	-18.63	-22.27	-19.93	-17.63
HV	-24.24	-26.29	-25.32	-29.19
ANGLE = 75 DEGREES RANGE 57.6984 TIME 1045				
HH		-23.77	-21.57	-20.90
HV	-26.69	-27.64	-28.32	-29.82
ANGLE = 40 DEGREES RANGE 16.9868 TIME 1054				
HH	-16.69	-20.50	-19.41	-16.05
HV	-23.90	-24.58	-26.36	-29.87
ANGLE = 50 DEGREES RANGE 20.5780 TIME 1059				
HH	-18.19	-21.25	-21.47	-17.80
HV	-24.94	-25.89	-26.76	-28.71
ANGLE = 75 DEGREES RANGE 51.2260 TIME 1105				
HH		-28.09	-25.51	-25.63
HV	-28.39	-31.88	-30.36	-33.52

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMA0 (dB)
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FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6
ANGLE = 40 DEGREES RANGE 16.9632 TIME 1112				
HH	-16.23	-19.91	-19.63	-16.38
HV	-23.40	-23.82	-23.87	-28.95
ANGLE = 50 DEGREES RANGE 19.5257 TIME 1118				
HH	-18.12	-23.90	-21.27	-19.50
HV	-24.92	-28.08	-27.13	-28.11
ANGLE = 75 DEGREES RANGE 55.9572 TIME 1124				
HH		-24.94	-22.63	-22.05
HV	-26.76	-29.61	-28.89	-29.58
ANGLE = 40 DEGREES RANGE 16.9947 TIME 1134				
HH	-14.80	-19.56	-17.99	-16.70
HV	-23.08	-23.77	-24.99	-27.85
ANGLE = 50 DEGREES RANGE 20.7102 TIME 1140				
HH	-19.35	-21.49	-20.70	-18.70
HV	-26.51	-26.44	-26.51	-29.62
ANGLE = 75 DEGREES RANGE 54.3127 TIME 1145				
HH		-25.63	-23.33	-22.80
HV	-28.00	-30.88	-29.49	-30.72

BROOKINGS, SOUTH DAKOTA 1979
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FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6

ANGLE = 40 DEGREES RANGE 16.8689 TIME 1159

HH	-14.75	-19.15	-19.46	-18.06
HV	-23.81	-23.02	-23.31	-27.40

ANGLE = 50 DEGREES RANGE 20.5725 TIME 1204

HH	-18.39	-21.65	-21.51	-17.68
HV	-24.86	-25.01	-26.80	-28.42

ANGLE = 75 DEGREES RANGE 57.5553 TIME 1210

HH		-24.26	-21.46	-21.04
HV	-26.04	-28.31	-27.55	-30.58

ANGLE = 40 DEGREES RANGE 17.2429 TIME 1216

HH	-15.39	-19.58	-18.73	-15.87
HV	-23.75	-24.57	-24.93	-27.24

ANGLE = 50 DEGREES RANGE 20.4853 TIME 1221

HH	-19.40	-21.50	-19.87	-17.90
HV	-25.84	-26.44	-26.43	-27.22

ANGLE = 75 DEGREES RANGE 57.9865 TIME 1227

HH		-24.57	-21.73	-21.38
HV	-26.62	-28.39	-27.22	-29.18

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMAO (dB)
STAUROLITE SNOWDRIFT

DATE 3/17/79
FREQUENCY (GHZ)

ANGLE = 40 DEGREES RANGE 17.0224 TIME 1233

	8.6	13.0	17.0	35.6
HH	-14.97	-19.45	-17.22	-15.65
HV	-22.70	-23.55	-24.88	-27.16

ANGLE = 50 DEGREES RANGE 19.7022 TIME 1239

	8.6	13.0	17.0	35.6
HH	-18.03	-23.76	-22.32	-19.26
HV	-24.79	-28.03	-26.68	-28.73

ANGLE = 75 DEGREES RANGE 58.1316 TIME 1245

	8.6	13.0	17.0	35.6
HH		-24.18	-21.03	-21.17
HV	-26.56	-28.08	-27.01	-28.27

ANGLE = 40 DEGREES RANGE 17.0901 TIME 1354

	8.6	13.0	17.0	35.6
HH	-15.34	-18.43	-18.82	-15.10
HV	-23.45	-23.58	-24.66	-26.41

ANGLE = 50 DEGREES RANGE 20.0832 TIME 1359

	8.6	13.0	17.0	35.6
HH	-18.65	-23.11	-20.86	-17.83
HV	-25.01	-26.32	-26.35	-27.66

ANGLE = 75 DEGREES RANGE 58.9420 TIME 1407

	8.6	13.0	17.0	35.6
HH		-21.81	-20.10	-19.59
HV	-25.51	-25.35	-25.19	-26.78

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMAO (dB)
STAUROLITE SNOWDRIFT

DATE 3/17/79
FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6

ANGLE = 40 DEGREES RANGE 16.6450 TIME 1627

HH	-15.98	-20.59	-17.38	-17.03
HV	-23.53	-24.21	-23.83	-25.49

ANGLE = 50 DEGREES RANGE 20.3502 TIME 1634

HH	-20.24	-22.49	-19.80	-16.71
HV	-26.69	-26.72	-27.72	-26.90

ANGLE = 75 DEGREES RANGE 58.5711 TIME 1639

HH		-20.29	-18.91	-19.72
HV	-24.13	-24.84	-24.14	-27.82

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMAO (dB)
STAUROLITE SNOWDRIFT (ROUGHNESS DATA)

DATE:3/19/79

FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6
ANGLE = 40 DEGREES RANGE 18.8460 TIME: 855				
HH	-19.70	-21.50	-21.30	-16.90
HV	-27.50	-26.70	-25.90	-26.00
ANGLE = 50 DEGREES RANGE 23.0175 TIME: 901				
HH	-20.90	-23.20	-21.70	-18.20
HV	-28.80	-28.60	-27.90	-26.30
ANGLE = 75 DEGREES RANGE 64.1096 TIME: 905				
HH	-19.50	-21.80	-20.90	-19.70
HV	-26.60	-25.90	-24.90	-26.30
ANGLE = 40 DEGREES RANGE 18.8318 TIME: 913				
HH	-19.80	-20.50	-19.50	-15.50
HV	-27.00	-26.70	-24.40	-26.80
ANGLE = 50 DEGREES RANGE 23.4027 TIME: 919				
HH	-20.40	-22.00	-21.60	-18.20
HV	-28.80	-27.50	-26.90	-27.80
ANGLE = 75 DEGREES RANGE 64.4697 TIME: 924				
HH	-19.20	-21.20	-21.50	-19.40
HV	-26.30	-25.50	-25.30	-26.20

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMAO (dB)
STAUROLITE SNOWDRIFT (ROUGHNESS DATA)

DATE:3/19/79

FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6
ANGLE = 40 DEGREES RANGE 18.8648 TIME: 932				
HH	-18.50	-20.80	-20.40	-17.40
HV	-26.60	-25.60	-25.10	-27.60
ANGLE = 50 DEGREES RANGE 22.9578 TIME: 937				
HH	-20.70	-22.40	-21.40	-17.20
HV	-28.70	-27.50	-26.20	-27.60
ANGLE = 75 DEGREES RANGE 62.5768 TIME: 942				
HH	-19.10	-20.00	-20.10	-20.10
HV	-24.70	-24.70	-24.40	-25.90
ANGLE = 40 DEGREES RANGE 18.7009 TIME: 1012				
HH	-12.00	-14.40	-14.70	-12.40
HV	-19.30	-19.80	-18.60	-21.70
ANGLE = 50 DEGREES RANGE 23.1514 TIME: 1018				
HH	-13.30	-15.80	-14.10	-14.90
HV	-22.00	-19.40	-20.30	-23.10
ANGLE = 75 DEGREES RANGE 61.3458 TIME: 1023				
HH	-17.60	-20.00	-18.10	-19.20
HV	-24.20	-23.30	-22.90	-25.50

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMAO (dB)
STAUROLITE SNOWDRIFT (ROUGHNESS DATA)

DATE:3/19/79

FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6

ANGLE = 40 DEGREES RANGE 18.7522 TIME: 1028

HH	-10.80	-13.80	-14.40	-12.70
HV	-18.80	-19.30	-19.50	-22.20

ANGLE = 50 DEGREES RANGE 23.9838 TIME: 1033

HH	-15.60	-14.50	-15.80	-13.80
HV	-22.50	-20.40	-21.00	-22.40

ANGLE = 75 DEGREES RANGE 60.3936 TIME: 1038

HH	-18.40	-21.20	-19.60	-20.50
HV	-24.90	-24.80	-23.60	-27.30

ANGLE = 40 DEGREES RANGE 18.7802 TIME: 1043

HH	-10.80	-13.90	-12.60	-10.90
HV	-19.50	-19.10	-18.20	-21.60

ANGLE = 50 DEGREES RANGE 23.2934 TIME: 1048

HH	-13.10	-14.30	-14.40	-13.50
HV	-21.50	-20.40	-20.50	-24.00

ANGLE = 75 DEGREES RANGE 61.7658 TIME: 1053

HH	-18.00	-18.80	-18.50	-19.40
HV	-24.40	-23.50	-23.30	-27.30

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMAO (dB)
STAUROLITE SNOWDRIFT (ROUGHNESS DATA)

DATE:3/19/79

FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6
ANGLE = 00 DEGREES RANGE 16.6260 TIME: 1128				
HH	3.80	1.80	-0.20	-2.50
HV	-3.80	-4.20	-7.30	-19.30
ANGLE = 10 DEGREES RANGE 17.1581 TIME: 1141				
HH	-1.00	-2.00	-3.60	-5.80
HV	-9.20	-7.70	-10.80	-20.20
ANGLE = 20 DEGREES RANGE 17.7409 TIME: 1153				
HH	-6.40	-7.90	-8.90	-9.70
HV	-13.80	-15.10	-16.00	-20.20
ANGLE = 00 DEGREES RANGE 16.6750 TIME: 1218				
HH	-4.60	-5.90	-7.10	-9.10
HV	-11.20	-10.90	-14.50	-19.90
ANGLE = 10 DEGREES RANGE 17.4268 TIME: 1236				
HH	-6.90	-8.10	-8.90	-9.80
HV	-13.80	-13.70	-14.80	-22.00
ANGLE = 20 DEGREES RANGE 18.2057 TIME: 1249				
HH	-8.20	-9.00	-10.50	-10.80
HV	-14.40	-14.40	-16.30	-21.00

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMAO (dB)
STAUROLITE SNOWDRIFT (ROUGHNESS DATA)

DATE:3/19/79

FREQUENCY (GHZ)

	8.6	13.0	17.0	35.6

ANGLE = 00 DEGREES RANGE 16.6184 TIME: 1418

HH	-4.30	-6.00	-7.50	-10.50
HV	-12.30	-12.90	-14.30	-21.50

ANGLE = 10 DEGREES RANGE 17.2529 TIME: 1431

HH	-7.70	-7.20	-11.10	-10.20
HV	-13.80	-13.00	-16.30	-19.20

ANGLE = 20 DEGREES RANGE 17.8090 TIME: 1442

HH	-8.00	-9.50	-11.10	-11.70
HV	-14.70	-16.00	-17.10	-19.10

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMAO (dB)
STAUROLITE SNOWDRIFT (SNOWPILES)

DATE: 3/21/79

FREQUENCY (GHz)

	8.6	13.0	17.0	35.6

ANGLE = 40 DEGREES RANGE 15.3911 TIME: 802 SNOW DEPTH: 0 cm

HH	-6.77	-7.04	-7.53	
HV	-14.57	-14.46	-13.89	

ANGLE = 40 DEGREES RANGE 15.1594 TIME: 812 SNOW DEPTH: 143 cm

HH	-10.97	-8.31	-7.88	
HV	-17.33	-13.56	-12.86	

ANGLE = 40 DEGREES RANGE 15.3577 TIME: 823 SNOW DEPTH: 51 cm

HH	-12.46	-13.46	-11.74	
HV	-20.23	-19.50	-17.75	

ANGLE = 40 DEGREES RANGE 15.3727 TIME: 834 SNOW DEPTH: 79 cm

HH	-13.24	-12.31	-11.32	
HV	-21.81	-18.97	-16.39	

ANGLE = 0 DEGREES RANGE 12.4615 TIME: 1038 SNOW DEPTH: 0 cm

HH	7.40	9.23	4.58	3.61
HV	-0.61	3.71	2.39	-8.36

ANGLE = 0 DEGREES RANGE 11.3632 TIME: 1004 SNOW DEPTH: 143 cm

HH	3.44	6.05	6.27	4.21
HV	-4.93	-2.63	-1.33	-18.66

ANGLE = 0 DEGREES RANGE 10.9916 TIME: 1025 SNOW DEPTH: 51 cm

HH	4.81	-1.80	2.72	0.78
HV	-4.25	-8.72	-5.45	-18.24

ANGLE = 0 DEGREES RANGE 11.2235 TIME: 1042 SNOW DEPTH: 79 cm

HH	5.67	-1.25	-0.19	0.23
HV	-4.97	-9.77	-9.89	-19.24

BROOKINGS, SOUTH DAKOTA 1979
SCATTERING COEFFICIENT SIGMAO (dB)
STAUROLITE SNOWDRIFT (SNOWPILES)

DATE: 3/21/79

FREQUENCY (GHz)

	8.6	13.0	17.0	35.6

ANGLE = 0 DEGREES RANGE 14.2859 TIME: 1508 SNOW DEPTH: 0 cm

	8.6	13.0	17.0	35.6
HH	2.47	2.45	0.58	-0.96
HV	-1.75	-0.99	-2.61	-5.97

ANGLE = 0 DEGREES RANGE 13.7807 TIME: 1530 SNOW DEPTH: 143 cm

	8.6	13.0	17.0	35.6
HH	-6.06	3.75	2.53	-6.87
HV	-12.19	-1.76	-3.98	-24.22

ANGLE = 0 DEGREES RANGE 14.1523 TIME: 1553 SNOW DEPTH: 51 cm

	8.6	13.0	17.0	35.6
HH	1.54	5.50	2.77	-0.69
HV	-5.49	-1.13	-3.25	-17.68

ANGLE = 0 DEGREES RANGE 13.5636 TIME: 1612 SNOW DEPTH: 79 cm

	8.6	13.0	17.0	35.6
HH	1.31	1.80	1.13	-4.74
HV	-5.32	-4.35	-5.13	-18.62

ANGLE = 40 DEGREES RANGE 19.7174 TIME: 1640 SNOW DEPTH: 0 cm

	8.6	13.0	17.0	35.6
HH	-5.84	-2.98	-4.62	-6.45
HV	-11.45	-9.87	-10.35	-11.55

ANGLE = 40 DEGREES RANGE 18.3667 TIME: 1650 SNOW DEPTH: 143 cm

	8.6	13.0	17.0	35.6
HH		-18.63	-18.58	-16.63
HV		-22.55	-22.39	-26.69

ANGLE = 40 DEGREES RANGE 19.1443 TIME: 1700 SNOW DEPTH: 51 cm

	8.6	13.0	17.0	35.6
HH		-20.81	-20.14	-15.69
HV		-24.79	-24.81	-26.94

ANGLE = 40 DEGREES RANGE 18.5945 TIME: 1710 SNOW DEPTH: 79 cm

	8.6	13.0	17.0	35.6
HH		-20.51	-18.45	-14.47
HV		-26.32	-23.76	-23.58